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Makalah REVIEW

Strategies for Indonesia's Agricultural Climate Change Adaptation and Mitigation

Strategi Adaptasi dan Mitigasi Perubahan Iklim Sektor Pertanian Indonesia

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Abstract. Agriculture contributes to and is a victim of climate change. Under the adverse impacts of climate change, producing more food is more challenging. The frequency and intensity of the occurrence of floods and droughts are increasing, which causes crop yield decline. Therefore, adaptation is a must to ensure agricultural resilience and food security. Adaptation strategies includes improvement of agricultural infrastructure, improved soil and nutrient management, the use of climate-extreme-tolerant varieties, improved livestock management, and improving farmers capacity in managing land. On the other hand, climate change is also affected by agriculture sector's emissions. Indonesian agriculture emitted about 104 Mt (million tonnes) CO_2e in 2020 with lowland rice, livestock enteric fermentation, direct N_2O from soil and manure, and indirect N_2O from soil as the main sources. Emission reduction strategies in Indonesia's First Nationally Determined Contribution (NDC) include the use of low-emission lowland rice crops varieties, implementation of efficient water management in lowland rice cultivation, manure management for biogas, and feed quality improvement for livestock. There are wider range of options of mitigation including intensified use of organic fertilizers, balance fertilization which is mostly associated with improving N use efficiency, and raising water table in peatland farming. Recently, the government launced the national climate change policy on the deep cut of emissions below that of the first NDC. These may include avoidance of using high carbon stock lands and enhancing carbon stocks of degraded lands. The majority of the mitigation options, as mentioned above, are in synchrony with adaptation, and vise versa, and this is the key in coping with climate change and maintenance of food security.

Keywords: Adaptation, Agriculture, Climate Change, Food security, Nationally Determined Contribution, Mitigation

Abstrak. *Pertanian merupakan salah satu sektor yang berkontribusi dan sekaligus menjadi korban perubahan iklim. Adanya perubahan iklim membuat pemenuhan kebutuhan pangan menjadi tantangan yang berat. Frekuensi dan intensitas kejadian banjir dan kekeringan semakin meningkat, yang menyebabkan penurunan hasil panen. Di sisi lain, perubahan iklim dipengaruhi oleh emisi dari sektor pertanian, sehingga adaptasi merupakan keharusan. Strategi adaptasi antara lain, perbaikan infrastruktur, perbaikan pengelolaan tanah, penggunaan varietas tanaman yang tahan terhadap iklim ekstrem, perbaikan pengelolaan ternak, serta peningkatan kapasitas petani dalam mengelola lahan. Pertanian Indonesia mengemisikan sekitar 104 Mt (juta ton)* CO_2e *pada tahun 2020 dengan sumber utama berasal dari sawah, fermentasi enterik dari ternak,* N_2O *langsung dari tanah dan pupuk kandang, dan* N_2O *tidak langsung dari tanah. Strategi penurunan emisi dalam the First Nationally Determined Contribution (NDC) adalah penggunaan varietas tanaman padi sawah rendah emisi, penerapan pengelolaan air yang efisien pada budidaya padi sawah, pengelolaan pupuk kandang untuk biogas, dan peningkatan kualitas pakan ternak. Selain itu, untuk mencapai target penurunan emisi nasional beberapa aksi dapat ditambahkan seperti intensifikasi penggunaan pupuk organik, pemupukan berimbang yang pada umumnya terkait dengan peningkatan efisiensi penggunaan N, dan peningkatan muka air tanah pada pertanian di lahan gambut. Dewasa ini pemerintah meluncurkan kebijakan tentang penurunan emisi yang lebih signifikan sampai di bawah komitmen First NDC. Ini antara lain dapat ditempuh dengan cara menghidari penggunaan lahan dengan cadangan karbon tinggi dan dengan meningkatkan cadangan karbon pada lahan terdegradasi. Pada umumnya opsi mitigasi, seperti disebutkan di atas, bersinergi dengan adaptasi, dan sebaliknya, dan ini merupakan kunci dalam menanggulangi perubahan iklim dan menjaga ketahanan pangan.*

Kata Kunci: *Adaptasi, Pertanian, Perubahan Iklim, Ketahanan pangan, Nationally Determined Contribution, Mitigasi*

INTRODUCTION

Agriculture is the most vulnerable sector to climate change, owing to its sensitivity to extreme and unpredictable weather parameters, thereby causing huge economic impacts. Climate change is altering temperatures, rainfall patterns, regional climate variability, sea level rise, and the incidence of extreme events (van der Wiel and Bintanja 2021; Avia 2019). Such changes influence agricultural productivity, water needs, production costs and the incidence of pests and diseases (Skendžić *et al.* 2021). Climate change threatens agriculture and food security of countries, especially those located near the equator, as tropical crops may be exposed to temperature beyond their high-temperature optima, thereby experience temperature stress (Malhi *et al.* 2021; Panfilova *et al.* 2020).

In recent decades, numerous weather and climate-related natural disasters have impacted Indonesia region repeatedly, demonstrating how vulnerable Indonesia's agriculture is to extreme climate events (Surmaini *et al.* 2015; Rondhi *et al.* 2019). . The Indonesian Ministry of Agriculture reported that during El Niño years of 1989-2020, damaged paddy area by drought ranged between 350 and 870 thousand ha, while during La Niña damage area due to flood ranged between 145 and 330 thousands ha. During 2005-2019, Indonesia experienced more than 78% hydro-meteorological disasters such as floods, droughts, forest fires and other extreme climates. Indonesia is the third largest country that experienced floods during 1900-2020 and the second highest death toll globally caused by disasters with 41.6 deaths per million populations from 278 events (DIBI-BNPB 2022). Without adaptation actions these climate threats may jeopardize crop productivity, and in turn, resulting in famines and food price increase (Gitz *et al.* 2016).

Agricultural activities also emit greenhouse gases (GHGs), especially methane (CH_4) and nitrous oxide (N_2O), as well as other substances that lead to ozone depletion in the atmosphere (Shakoor *et al.* 2020). The main sources of emissions in agricultural sector included CH_4 from lowland rice, enteric fermentation from livestock, direct N_2O from soil and manure and indirect N_2O from soil (IPCC 2019). Since GHG emissions are closely tied to population growth, it is imperative to act now to mitigate emissions and at the same time adapt to climate change, because agricultural sector is under pressure to increase production as the population continue to grow (Smith and Olesen 2010).

Climate change is projected to worsen in the upcoming future. The extremes in weather parameters, mainly minimum temperature, maximum temperature, and precipitation, are projected to occur more frequently and in higher intensity (Siswanto 2016; Supari *et al.* 2016). Hence, it's very important to keep the global warming below 1.5 ºC by 2050, relative to the pre-industrial era, to lower weather extremes (IPCC 2021). An increase in the atmospheric concentrations of GHG produces a positive climate forcing or warming effect (Manabe 2019). For that reason, there is a need for this sector to reduce the amount or intensity of GHG emissions.

Agriculture has always been adapting to climate with regionally specific adapted systems being observed across the world (Baul and Mc Donald 2015; Limpo *et al.* 2022). However, the pace of climate change is much faster recently than in the earlier history (IPCC 2022). Small and marginal farmers are not able to cope with climate change due to the lack of means to adapt and lack of information, which makes them more susceptible (Morton 2007). Therefore, adaptation should be the priority in order to maintain resilience to climate change and safeguarding food security. Some adaptation responses involve significant co-benefits, synergies and trade-offs. In many cases, adaptation may also contribute to mitigation (Akinyi *et al.* 2021).

There are policies on adaptation and mitigation at the global (United Nations Framework Convention on Climate Change, UNFCCC) level. Meanwhile, there are regulations imposed by importing countries with a focus on mitigation, and alongside those international policies there are national policies that may emphasize adaptation, mitigation, or a balance of both, depending on the country's circumstance (Republic of Indonesia 2021). Under the Nationally Determined Contribution (NDC), Indonesia must reduce its total emissions by 29% (unilaterally) or 41% (with foreign aid) by 2030 relative to the Business as Usual (BAU) level (Republic of Indonesia 2021). However, achieving this target is challenging, as a country with a dense population, Indonesia must ensure food sustainability by maintaining its agricultural production. In order to reduce emissions, countries need to prepare and implement a range of policies and instruments (Tacconi and Muttaqin 2021).

This article starts with a general overview of Indonesia's agriculture and how vulnerable it is to climate change. Discussion is followed by policies on adaptation and mitigation from the global to national levels. This article concludes with the challenges in addressing those policies.

Indonesia's agriculture and its vulnerability

From the total land area of 187.8 million hectares (Mha), 62.3 is used for agriculture, 92.7 is for forests, and the rest is for various uses (FAOSTAT, 2019). Indonesia's agriculture varies widely in terms of the crops being cultivated, the edaphic factors, the climate, and the socio-economic backgrounds of the farmers. As such, the vulnerability to climate change also varies, not only determined by the biophysical, but also farmers' socio-economic circumstances.

Lowland rice area is about 7.1 million ha (Decree of the Minister of ATR/Head of BPN-RI Number 339/2018). A more recent, but unpublished data mentioned that the lowland rice area is about 7.46 million ha, while the harvest area between 2019 to 2021 ranged from 10.4 to 10.7 million ha (bps.go.id), meaning that, on average, harvesting intensity is about 1.4 times per year. For other crops, such as maize, soybean, and various vegetables, the "standard" area is not easy to define since many of those crops share the same piece of land with lowland rice during the dry season (Agus *et al*. 2019). For instance, maize could be planted in a rotation with rice in an irrigated or rainfed system. In the upland it is likely to be in rotation with other crops too, such as peanut, soybean, or vegetable crops (e.g. Santoso *et al*. 2021). The area tends to decrease due to conversion to non-agricultural uses (Mulyani *et al*. 2016; Andrade *et al*. 2021). Updated data is not available, but the 2015 figures of harvested areas (Mha) were 3.75 for maize, 0.61 for soybean, 0.45 for peanut, 0.95 for cassava, and 0.14 for sweet potato (bps.go.id). The irrigated lowland rice areas, lowland rainfed areas, and the upland areas are vulnerable to drought, floods, and strong winds because of short and frangible shoots and roots (Surmaini and Agus 2020).

Besides the crop types, where annual crops are relatively more vulnerable, the geographical location determines vulnerability. With thousands of small islands, the long coastal areas of Indonesia are expected to encounter severe impacts from sea level rise. NOAA (2020) estimated that Indonesia experienced a sea level rise of 3.9±0.4 mm year^{-1} between 1992 and 2020. Rice fields which are dominant in its coastal areas are very vulnerable to inundation. This may contribute to a loss of arable land through inundation and increased soil salinity, affecting crop growth and yield (Kamran *et al.* 2019). An increase in sea level of up to 1 m will cause coastal areas currently 1 m above sea level to be inundated, impacting 134,509 ha of rice fields throughout Indonesia, of which 51% is located in the island of Java. This event will potentially cause an annual loss of rice production of up to 976,688 tons (Surmaini *et al*. 2022).

The high salt content of seawater contaminates agricultural soils and groundwater, imposing constraints on the growth and production of rice. Based on 2017 data from Java island, more than half million hectares of rice fields sufferred salinity problem due to seawater intrusion, with the average rice yield during the dry season about 0.65 t ha^{-1} lower than that during the wet season (Sembiring *et al*. 2019). Any increase in salinity will reduce rice production exponentially. An increase in electric conductivity (EC) of up to 4 dS m^{-1} may cause a loss of 1,835 tons of dry unhusked rice production annually (Surmaini *et al*. 2022).

Tree based horticultural crops such as orchard farming is another important type of Indonesian agriculture. Like many food crops, defining the areas for tree based horticultural crops is not easy, because many trees are located at home gardens and likely intercropped various other tree crops in agroforestry systems (Abdoellah *et al*. 2020). Large scale and monoculture fruit trees are not common. However, despite its relatively small scale, in aggregate, fruit tree crop systems store a significant amount of carbon. These crops, being tree crops, are relatively more resilient to extreme weather events such as floods, droughts and strong winds. (Marland and Marland 1992).

Like fruit tree crops, annual vegetable crops such as tomatoes, potatoes, carrots, broccoli, cabbage belong to horticultural crops. They are mostly planted on high elevation areas which are usually associated with steep slopes, high rainfall, and volcanic ash derived soils. The soil is deep and high in organic matter (Sukarman and Dariah 2015), but the steep landform and the high intensity and high amount of rainfall threaten soil conservation. Furthermore, the higher frequency of weather extremes, such as torrential rains (Surmaini and Faqih 2016) make the steep slope agriculture more vulnerable to water erosion (Agus and Widianto 2004).

Plantation crops develop relatively rapidly, but the expansion is dominated by oil palm and, to some extent, cacao (Figure 1). Oil palm plantation area increased from 4.2 million ha in 2000 to 14.9 million ha in 2020. Cacao has expanded from about 0.6 million ha in 2000 to about 1.5 million ha in 2020. Oil palm has a very high adaptability on acid soils, including very acidic peat soils. The main prerequisite is high annual rainfall of at least 1750 mm year^{-1} with no distinct dry months (Djaenudin *et al*. 2003). However, cacao requires less acidic soils with deeper solum (Aini *et al*. 2020).

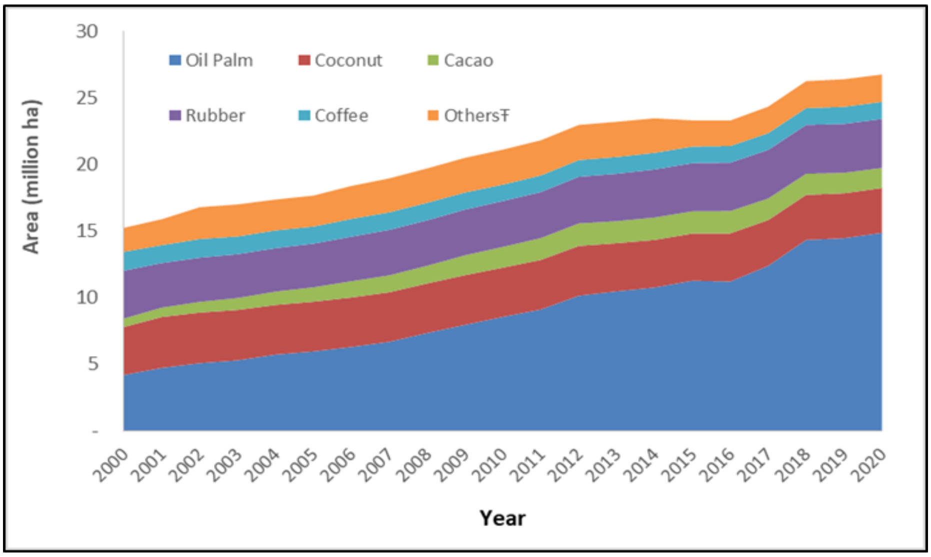

Figure 1. Areas of selected plantations from 2000 to 2020 (data processed from bps.go.id). ŦOthers include tea, kapok, cashew nut, nutmeg, cinnamon, candlenut, betel nut, pepper, vanilla, clove, sugar cane, tobacco, lemon grass, castor, and patchouli

Gambar 1. Areal perkebunan tahun 2000 sampai 2020 (data diolah dari bps.go.id). ŦTanaman lainnya antara lain teh, kapuk, jambu mete, pala, kayu manis, kemiri, pinang, merica, vanili, cengkeh, tebu, tembakau, serai, jarak, dan nilam

Most plantation crops are tree crops with long life cycles and relatively high carbon stocks. When they are planted on degraded lands, which are mostly having low carbon stocks, such as grasslands or shrubs, the plantation crops sequestrate carbon by changing the landscape with low to moderate or high carbon stocks (Agus *et al*. 2013).

In general, the perennial plantation crops can withstand droughts and floods better than annual crops, due to their deep root distribution and tall stems such that they are not easily inundated, nor do they easily dry during the dry period due to their long roots (Basche and Edelson 2017). Moreover, perennial crop plantation provides other ecosystem services, besides carbon storage, including soil erosion control, biodiversity protection, water regulation, and wood production (Hua *et al*. 2022). Despite the more resilient and mitigating capacity of perennial crops, land suitability and market demands should be taken into consideration in perennial crop plantation development.

Urgency of Adaptation and Mitigation

The IPCC Assessment Report 6 (IPCC AR6) published several books related to scientific basis of climate change, adaptation, mitigation, as well as improved methodology of GHG inventories (https://www.ipcc.ch/). IPCC (2019a) demonstrated the trend of anthropogenic warming and the maximum increase that can be managed through adaptation and mitigation. Under the Paris Agreement, in which countries pledged to reduce emissions as stipulated in their Nationally Determined Contribution (NDC), the temperature increase will be exceeding 2 °C by 2100, relative to that of the pre-industrial era. To be manageable the temperature increase by 2100 should not exceed 1.5 °C, beyond which adaptation will be too difficult and too costly to do. Hence a series of “deep cut” carbon emissions scenarios must be implemented such that the global average atmospheric temperature will not exceed 1.5 °C by 2100.

IPCC (2019b) explained the relationship between climate change and land, i.e. how climate change affects lands, including the farming systems, and how improved land management could improve adaptation capacity of different farming systems, and at the same time can potentially mitigate climate change.

To be able to limit the temperature increase below 1.5 °C the global net human-caused emissions of carbon dioxide (CO_2) need to fall by about 45 percent from 2010 levels by 2030, reaching ‘net zero’ around 2050 (Figure 2). This means that any remaining emissions would need to be balanced by removing CO_2 from the air” (IPCC 2019b).

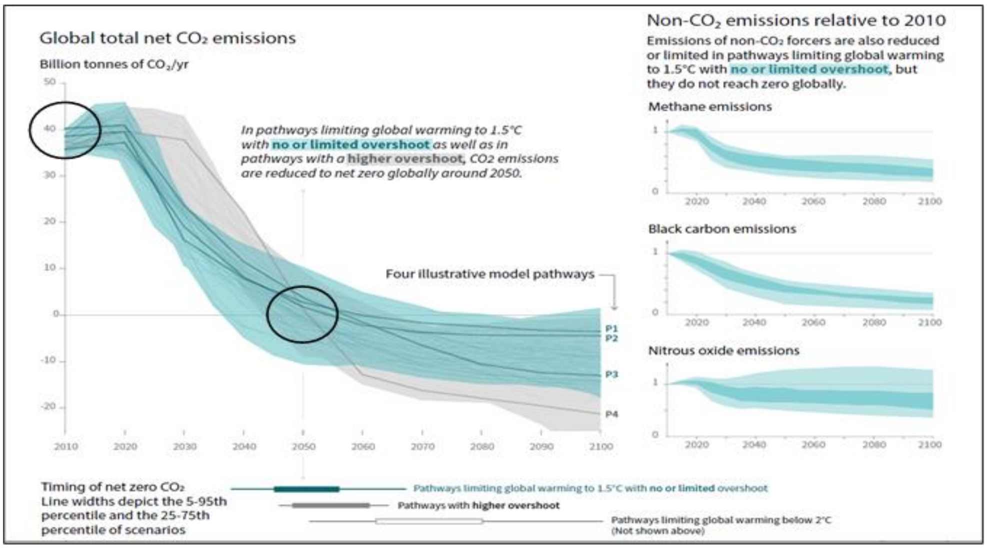

Figure 2. Historical (1960-2017) and predicted (2017-2100) temperature increase under different scenarios (IPCC 2019b)

Gambar 2. Peningkatan suhu historis (1960-2017) dan prediksi (2017-2100) dengan beberapa skenario (IPCC 2019b)

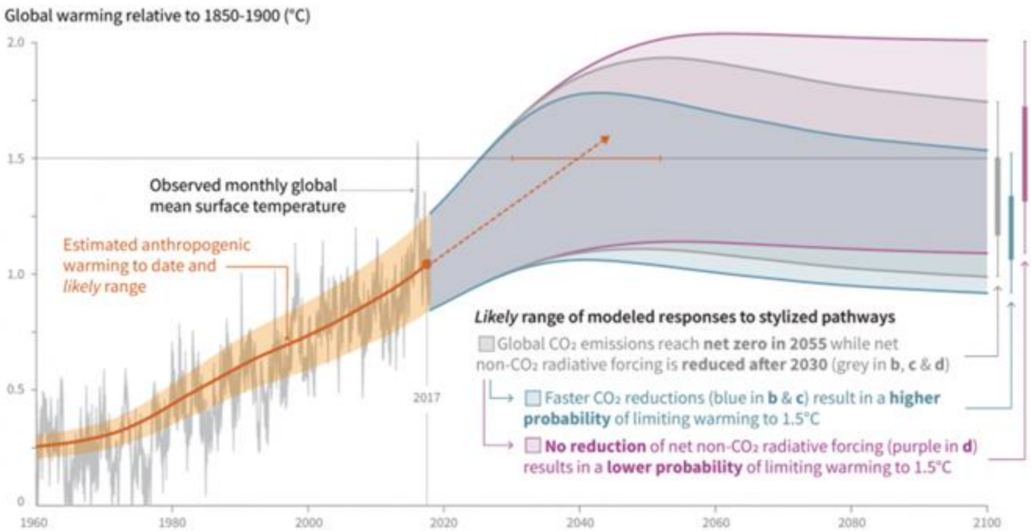

Figure 3. Global emission reduction pathways for net zero emissions scenarios by 2050 for limiting the global warming below 1.5 ºC (IPCC 2019b)

Gambar 3. Jalur penurunan emisi global untuk mencapai net emisi nol menjelang tahun 2050 untuk menekan pemanasan global di bawah 1,5 °C (IPCC 2019b)

In Glasgow's United Nations Climate Change Conference (COP 26) it was agreed that the mitigation relies highly on the energy sector, especially through phasing out the use of non-renewable fuels. COP 26 also discussed intensively about phasing out of coal, and this proposal was responded differently among the producers and consumer countries. Economic consequences and countries' readiness to replace this energy source with non carbon-based fuels vary a great deal.

The pathways to limit global warming to 1.5°C with limited or no overshoot, bioenergy with carbon capture and storage (BECCS) deployment is projected to range from 0–1, 0–8, and 0–16 Gt CO_2 yr^{-1} in 2030, 2050, and 2100, respectively, while Agriculture, forestry and land uses (AFOLU) related Carbon Dioxide

Table 1. Historical and projected greenhouse gases emissions from different sectors and different scenarios based on Indonesia's first Nationally Determined Contributions (Republic of Indonesia 2021)

Tabel 1. Emisi gas rumah kaca historis dan proyeksi dari berbagai sektor dengan beberapa scenario berdasarkan Nationally Determined Contributions Indonesia yang pertama (Republic of Indonesia 2021)

Sector	GHG emission level 2010* (M tonnes CO_2e)	GHG Emission level 2030 Mt CO_2e			GHG Emission reduction Mt CO_2e		GHG Emission reduction % of total BAU		% Annual average growth BAU (2010-2030)
		BaU	CM1	CM2	CM1	CM2	CM1	CM2	
1. Energy*	453.2	1,669	1355	1,223	314	446	11	15.5	6.7
2. Waste	88	296	285	256	11	40	0.38	1.4	6.3
3. IPPU	36	70	67	66	3	3.25	0.10	0.11	3.4
4. Agriculture **	**111**	**120**	**110**	**116**	**9**	**4**	**0.32**	**0.13**	**0.4**
5. Forestry and other Land Uses (FOLU)***	674	714	217	22	497	692	17.2	24.1	0.5
Total	1,334	2,890	2,034	1,683	834	1,185	29	41	3.9

Notes: BAU is the business as usual scenario, CM1 is the unconditional counter measures which is based on national efforts, CM2 is conditional counter measures, for which the scenario can be realized through international collaboration. GHG = Greenhouse gases.
**) Including fugitive*
***) Only include rice cultivation and livestock*
****) Including emissions from estate crop plantations*

Removal (CDR) measures are projected to remove 0–5, 1–11, and 1–5 $GtCO_2$ yr^{-1} in these years (IPCC 2019a). The upper end of these deployment ranges by 2050 exceeds the BECCS potential of up to 5 Gt CO_2 yr^{-1} and afforestation. BECCS is not agreed by some demand-side countries and their measures rely on greater AFOLU-related CDR measures. However, the use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors.

CDR is not an easy subject. The measure could have significant impacts on land, energy, water or nutrients if deployed at large scale. Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity, and other ecosystem functions and services. Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require governance systems enabling sustainable land management to conserve and protect land carbon stocks and other ecosystem functions and services (Berg 2019).

Figure 3 shows the pathways for achieving net zero emissions by 2050. As shown on the right hand side panel, while net zero emissions is impossible for methane, black carbon, and nitrous oxide, much of which is related to agriculture, but at the global level these emissions can be reduced by various ways such as alternate wetting and drying (for CH_4 from flooded rice system), and balance fertilization to improve nitrogen use efficiency (IPCC 2019b). However, in developing countries CH_4 and N_2O emissions may increase to address the deficit of meat consumption and to adjust fertilizations in accordance with crop needs, respectively (McMichael *et al.* 2007; Kim *et al.* 2021).

The Nationally Determined Contribution and the Position of Agriculture

1. Mitigation

Based on Indonesia's updated First Nationally Determined Contribution (1st NDC), the GHG emissions of Indonesian Agricultural Sector in 2010 were around 111 million tons (Mt) CO_2e, the third highest after Forestry and Energy (Table 1). Under the business as usual (BAU) scenario, the emissions from agriculture sector in 2030 will moderately increase to 120 Mt CO_2e. With counter measure 1 (CM1) that relies on the national efforts, the emissions in 2030 are estimated at 110 Mt of CO_2e (about 9 Mt CO_2e lower than the BAU level). At the same time this value also approaches the historical 2010 emission. Under CM2, i.e., the scenario strengthened by international cooperation, emissions in 2030 are estimated to be 116 Mt CO_2e, which is about 4 Mt CO_2e lower than BAU, but about 6 Mt CO_2e higher than the CM1. This shows that increasing agricultural efforts in dealing with climate change may focus more on adaptation, and this is not necessarily effective in reducing GHG emissions, rather, it is expected to improve agricultural resilience against climate change.

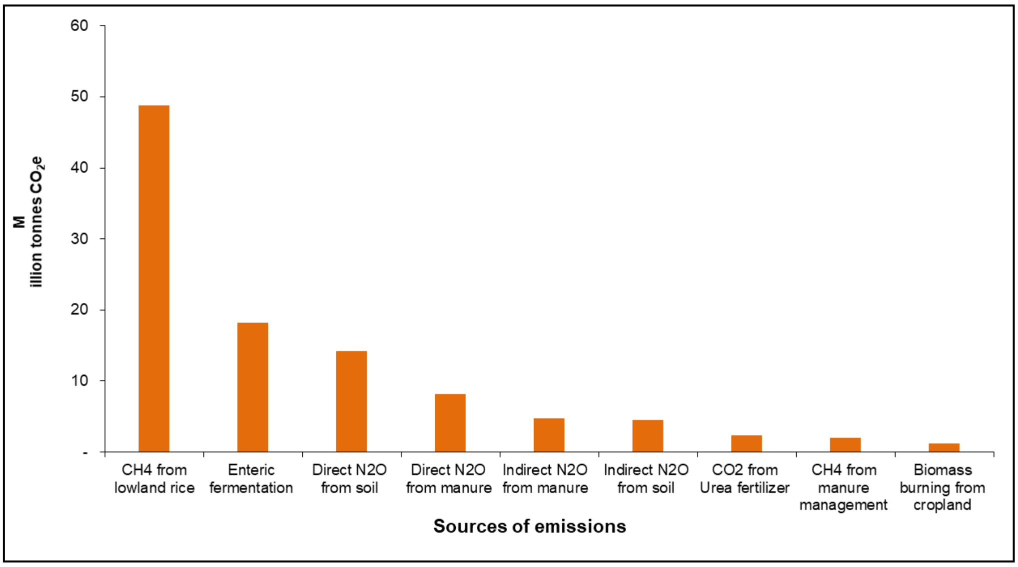

Figure 4. Emissions from various sources in agricultural sector in 2020. The total national emissions from agriculture were 104 Mt CO_2e, which was already below the business as usual level of 2030 (ICARLD 2021)

Gambar 4. Emisi dari berbagai kategori kunci pada sektor pertanian tahun 2020. Total emisi nasional dari pertanian adalah 104 Mt CO_2e, dimana emisi tahun tersebut sudah berada di bawah level business as usual 2030 (ICARLD 2021)

Table 2. Emission reduction strategies in agricultural sector and assumptions used in the First Nationally Determined Contribution (Republic of Indonesia 2021). BAU is the business-as usual scenario, CM1 is the unconditional counter measure which is based on national efforts, CM2 is conditional counter measure, achievable through international collaboration.

Tabel 2. Strategi dan asumsi pengurangan emisi untuk sector pertanian yang digunakan dalam Nationally Determined Contribution pertama (Republic of Indonesia 2021). BAU adalah skenario business-as-usual, CM1 adalah penurunan emisi berdasarkan pada upaya nasional, dan CM2 adalah penurunan emisi melalui kerjasama internasional

No	Mitigation measures in agricultural sectors	BAU	CM1	CM2
1.	The use of low-emission lowland rice crops varieties.	No mitigation actions.	In total, the use of land for low emission crops is up to 926,000 hectares in 2030*.	In total, the use of land for low emission crops is up to 908,000 hectares in 2030*.
2.	Implementation of efficient water management in lowland rice cultivation.	No mitigation actions.	Implementation of water efficiency is up to 820,000 hectares in 2030*.	Implementation of water efficiency is up to 820,000 hectares in 2030*.
3.	Manure management for biogas.	No mitigation actions.	Up to 0.06% of the total cattle in 2030**.	Up to 0.06% of the total cattle in 2030**.
4.	Feed supplement for cattle.	No mitigation actions.	Up to 2.5% of the cattle population in 2030**.	Up to 2.5% of the cattle population in 2030**.

The main sources of emission in agricultural sector included CH_4 from lowland rice, enteric fermentation from livestock, direct N_2O from soil and manure and indirect N_2O from soil (Figure 4). There are cross-sectoral sources of emissions, such as emissions from agriculture, forestry and land use (AFOLU), including emissions from peatlands. The AFOLU sector is inventoried by the Ministry of Environment and Forestry and this includes land use change to agriculture.

We recognize the potential emission reduction from improved water management in peatland by raising the water table of the drained peatland, for instance by constructing canal blocks (Urzainki *et al.* 2020). Until present, this aspect has not been recorded as part of the regular mitigation achievement in Indonesia, but now temporarily inventoried by the Ministry of Agriculture.

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During the early development of the 1st NDC, interventions in agricultural sector were limited to only livestock and paddy rice and with the very small amount of emission reduction contribution (Table 2). In the following paragraphs, we briefly discuss the interventions as shown in the 1st NDC (Table 2) and how relevant they are now.

1.a. The use of low emission crops.

There are two or more simultaneous processes taking place along with this intervention. Besides the use of low CH_4 emission rice varieties, there was also an effort to increase planting/harvesting intensity from 2.11 to 2.5 in Java and from 1.7 up to 2.0 outside of Java islands. These prolonged cropping seasons are expected to result in an increased planting area, and hence the period of inundation under the conventional flooded rice management, and hence, increased CH_4 emission. The actual data showed that the increase in cropping intensity did happen in 2015, 2016, and 2017, but it dropped again in 2018, 2019 and 2020 (unpublished data in Indonesian GHG Inventory for agricultural sector). Another optimistic assumption which is not valid anymore, was that all paddy fields outside Java would have been improved to irrigated paddy systems by 2030. Until present, there is no strong indication of such development, and most of rainfed areas will likely be under rainfed management for some time in the future.

The use of low emission varieties potentially contributes to mitigation (Gutierrez *et al.* 2013) and this is related to different root exudates produced by the different varieties (Aulakh *et al*. 2001), as well as the different community structure of methane producing bacteria (Eller and Frenzel 2001). In Indonesia, IR64 is a conventional variety with emission of one rice cycle of 202.3 kg CH_4 ha^{-1}. The more popular variety recently is Ciherang with CH_4 emission rate of 0.57 of the IR64 (the average CH_4 emission of IR64 is 202.3 kg ha^{-1} $season^{-1}$). Hervani *et al*. (2019) provided a list of 40 varieties, the length of each variety crop cycle, average yield, and scaling factor for CH_4 emission calculation.

It's important to note that in practice, in the selection of rice varieties, the CH_4 emission factor is not taken into consideration neither by the government, nor by farmers. The main consideration is the yield and rice quality that the varieties can offer. While Ciherang meets all three criteria (low emissions, high yield, and good quality rice), low CH_4 emission varieties may not always associate with high yield and high-quality rice, depending on the future rice genetic development.

1.b. Efficient water management

This intervention is realized in the forms of intermittent irrigation, flooding during the vegetative growth and drying during the generative phase of rice, and the system of rice intensification (SRI) (Uphoff *et* al. 2015). In doing so, not only the use of water becomes more efficient, but CH_4 emissions also decrease due to reduced number of flooding days. One of the approaches of SRI that reduce CH_4 emission is water management, in which the soil is kept moist during cultivation, but not flooded in most of the cropping season. Studies have shown that reduced number of flooding days through intermittent irrigation or alternate wetting and drying (AWD) reduced methane emissions by 22% to 64% (Suryavanshi *et al.* 2013, Choi *et al*. 2014, Jain *et al.* 2014).

Hidayati *et al*. (2016) claimed an impressive 24% yield increase under the System of Rice Intensification (SRI), while Thakur *et al*. (2013) claimed yet another higher yield increase of 48% under SRI, compared to the conventional flooding system. However, Glover (2011) argued that the claim of yield improvement under SRI has been controversial and this was mainly due to the lack of standardized description of SRI. The adoption of SRI varied depending on the farmers' backgrounds. A case study in Timor Leste revealed that the more knowledgeable the farmers about the system and the higher the availability of labour, the higher the adoption of SRI, since SRI is not very simple and it's a labour demanding technique (Noltze *et al.* 2012). Some farmers also perceive that most rice varieties grow better and produce higher yield when grown under flooded soil. Reduced yields and pest control problems (primarily nematodes and weeds) associated with AWD is one of the challenges to be addressed (Kreye *et al.* 2009). AWD is conducive to the germination and growth of weeds causing grain yield losses of 30 to 98% (Ramana *et al.* 2014). Moreover, another challenge on AWD is that the farmer's fields do not get access to water at the time when it is needed (Kürschner *et al.* 2010).

1.c. Manure management for biogas

The assumption of adoption of 0.06% in 2030 (Table 2) is very low and very conservative because it was based on a small-scale biogas program using small digestion tanks. There is a potential for further development of this program, but the success also depends on the price of conventional fuels. Maintenance and gas piping systems are not simple for villagers to manage, and hence continued supervisions for this initiative will be necessary to ensure maintenance.

1.d. Improved feed quality for livestock

The most common feed supplement for livestock, including cattle, is mixing grass with high protein fodder, such as those of leguminous origin, as well as concentrate (Hristov *et al.* 2013). These supplements not only improve feed quality, and hence livestock production, but also reduce CH_4 emission from enteric fermentation. Again, what is assumed in the NDC are small scale demonstration programs. The impact of the demonstration to the surrounding areas has not been taken into account. Voluntary adoption by farmers has not yet recorded because of difficulties in activity data collection.

In addition to the above four interventions listed in Indonesian 1st NDC, the annual reporting of GHG emission reduction by the Ministry of Agriculture (reported in KLHK 2020) also included:

1.e. Intensified use of organic fertilizers.

This intervention is expected to increase soil carbon stock (e.g. Yan *et al.* 2022) and improve soil health.

1.f. Balance fertilization.

Balance fertilization is mostly associated with improving N use efficiency. This intervention is especially suitable for areas with overuse of subsidized nitrogen fertilizers. However, there are also areas with underuse of N fertilizers where increasing fertiliser uses, not only N, but also P and K, should be prioritized to enhance production. If this program is successful the aggregate national N_2O emission may increase, but the adaptive capacity of agriculture will increase.

1.g. Raising water table on peatland.

Drained peatland is a major source of CO_2. An approach to reducing emission is by raising water table by canal blocking (Urzainki *et al.* 2020). This item is not included in KLHK (2020), but a prospective approach considering a high contribution, should the monitoring is done regularly.

2. Adaptation

At the 23rd Conference of the Parties (COP) in 2017 as a new process to advance discussions on agriculture in the United Nations Framework Convention on Climate Change (UNFCCC), the parties agreed on a roadmap called the Koronivia Joint Work on Agriculture (KJWA). The KJWA addressed several topics included improved soil management, nutrient use, water management, livestock management, methods for assessing adaptation, and the socio-economic and food security dimensions. Due to its main role to achieve food security, and as has been outlined in the KJWA agreement, adaptation is the priority in agriculture.

Mitigation could be aimed as a co-benefit of adaptation. With the same token, adaptation should be regarded as the entry point, and as much as possible, measures that address adaptation, has positive impacts on mitigation. The KJWA outlined that improving soil and nutrient management, including the use of organic fertilizers and manure, is important in increasing agricultural resilience to climate change, creating sustainable food production systems, and achieving global food security dimensions of climate change in the agricultural sectors (FAO 2018).

Following the completion of the series of KJWA Workshop, Indonesia emphasizes the importance of speeding up the implementation. The Indonesian government recognizes the importance of providing the means of implementation as a prerequisite for adaptation implementation (KLHK 2020)

A number of adaptation and mitigation strategies have been developed to offset the deleterious impact of climate change on agricultural sustainability known as Climate Smart Agriculture (CSA). CSA aims to adapt to climate change by adopting several interventions,

Table 3. Adaptation activities in agricultural sector (adapted from BAPPENAS 2021)
Tabel 3. Kegiatan adaptasi pada sektor (diadaptasi dari BAPPENAS 2021)

Cluster	Activities
Infrastructure	1) Development of water storage (dams, ditches, long storage); 2) Development of irrigation networks through: (a) construction of tertiary irrigation networks on agricultural lands, (b) new developments or modifications of irrigation systems into pipe irrigation, drip irrigation, and sprinklers; 3) Provision of flood protection construction, such as polders in paddy field areas and river embankments around agricultural lands; 4) Provision of adaptive farm supplies and equipment such as superior plant seeds with high productivity and resistance to climate stress and pests, organic fertilizers, pest control facilities, and machinery to increase labour efficiency; and 5) Extensification of paddy fields and other agricultural areas on low carbon and abandoned land.
Technology	Implementing technologies: 1) Tolerant varieties against drought, floods, salinity, and pests and diseases 2) Agricultural machinery, for overcoming labour shortage 3) Intermittent irrigation system and low emission rice varieties with high productivity; 4) Organic matter application, 5) Improvement of manure management; 6) Balanced fertilization 7) Soil conservation techniques on mineral soils 8) Improved water management systems on peatlands for reducing the risk of fires and GHG emissions 9) Reducing land extensification in areas with high C storage and planting crops with high C storage in areas with low C stock such as shrubs.
Capacity Building	1. Increasing community awareness on the danger of climate change 2. Farmer's counselling and assistance, including technical guidance on climate-resilient and low-carbon agriculture.
Governance and funding	1) Climate insurance 2) Access to credit and finance 3) Labour intensive scheme 4) Regulation

including water-smart practices, nutrient-smart practices, weather-smart activities, carbon-smart activities, and knowledge-smart activities (Malhi *et al*. 2021) while at the same time, minimize the amount of emissions. Several of these actions and policies already exist in the Indonesian agricultural sector, but implementation in the field need to be enhanced because CSA is very important to increase the resilience of the agricultural system and food security (Simarmata *et al.* 2020).

BAPPENAS (2021) launched a policy recommendation document entitled Climate Resilient Development Policyas a guideline for coping with climate change for local and regional governments, as well as related institutions to implement the Medium-Term National Development Plan (RPJMN) 2020-2024. In the 2020-2024 RPJMN, increasing climate resilience is targeted to reduce potential economic losses from the impacts of climate change by 1.15 percent of GDP by 2024. Climate resilient development policies are in line with the Sustainable Development Goals (SDGs), Low Carbon and Climate Resilience Strategy, Sendai Framework, and fulfilment of Paris Agreement goals.

In carrying out climate-resilient development implementation actions, the government established programs and activities on infrastructure development, technology implementationtechnology, capacity building, and improved governance and funding (BAPPENAS 2021). For the agricultural sector, the Ministry of Agriculture classifies adaptation activities as follows (1) development and maintainance of agricultural infrastructure (2) implementation of adaptation technology with mitigation co-benefits, (3) research and development of adaptation and mitigation; (4) capacity building; and (5) governance and funding of climate change actions (Ministry of Agriculture 2021) as described in Table 3. Further more, sustainable intensification is very important to increase yield and reduce the pressure to extensification (Grassini *et al*. 2015), and hence reduce GHG emissions from land use change (Monzon *et al*. 2021).

Increasing Mitigation Ambition above NDC

Along with the accord of United Nations Climate Summit in Glasgow, in 2021, in which there is a pressing need to increase ambition of greenhouse gases mitigation, and that by 2050 several developed countries commit to achieve net zero emissions, Indonesia issued Presidential Decree (PERPRES 98/2021) emphasizing the importance of carbon economic value (NEK), which was then translated as carbon Cap-Trade-Tax. It is important to note that for agricultural sector, as discussed under the KJWA, mitigation is not the main target. The KJWA agreement emphasizes the importance of improving agricultural resilience by improving adaptation measures such that this sector can maintain its role to ensure food security. Mitigation is aimed at, along with adaptation.

Since the presidential decree is intended to increase mitigation ambition above that of NDC, the measures under NDC are considered as the "Cap" (the new baseline). If a business sector can lower the emissions below the NDC Cap target, it can sell the carbon credit to other companies that are yet to increase their mitigation achievement. Likewise, if a company fails to achieve emission reduction target and its emission level is not lower than the cap, then it must pay Tax (offset the emission) based on the difference between the Cap and the achieved emission level. For the initial step Indonesia chose \$3 per tonne CO_2e for the carbon Trade and Tax.

This carbon trading system may be very complicated for smallholder farmers due to very small scale farms (ranging from a fraction of hectare to a few hectares) and because of highly variable farm practices found in the fields. However, it has a potential for large scale plantations. The challenge is setting up the standardized methodologies for life cycle analysis (LCA) of GHG emissions (Bessou *et al*. 2014). This increased ambition could be achieved by limiting further land use change for agriculture only on lands with low carbon stock, rehabilitation of degraded-abandoned lands, and improvement of vegetation composition of grasslands by introduction of leguminous forages and trees.

CONCLUSIONS

Worsening climate change has put a lot of pressure on agriculture in sustaining food security. Agricultural sector is very vulnerable and a victim of climate change, and therefore, Indonesian agriculture must prioritize adaptation to ensure resilience to climate change and maintain food security. By adapting, it is hoped that there will also be a reduction in GHG emissions as co-benefits.

A number of adaptation and mitigation strategies, known as Climate Smart Agriculture (CSA), have been developed to offset the adverse impact of climate change. There are opportunities for increasing CSA implementation, as long as the means of implementation is ensured. In addition, greater opportunities for increasing NDC's ambition could be realized if a cross-sectoral approach, especially between agriculture and forestry, can be enhanced in relation to developing new agricultural lands only on low carbon stock lands.

Emission reduction strategies in Indonesia's Nationally Determined Contribution (NDC) include the use of low-emission lowland rice crops varieties, implementation of efficient water management such as alternate wetting and drying in lowland rice cultivation, manure management for biogas, feed quality improvement for livestock, intensive use of organic fertilizers, balance fertilization, raising water table in peatland farming, controlling land use change from high carbon stock areas, rehabilitation of degraded-abandoned lands, and improvement of vegetation composition of grasslands by introduction of leguminous forages and trees.

Sustainable intensification of agriculture for increasing crop yield on existing agricultural lands can also contribute to emission reduction from indirect land use change.

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