CLIMATE SMART AGRICULTURE IN INDONESIA

Final Submission – March 7, 2021

Highlights

1. While the agricultural sector will generate a smaller share of Indonesia's GDP over time, it is of critical importance for livelihood generation and food security. To future-proof the sector, significant investment is required to help smallholders adapt to the increasingly severe impacts of climate change. The value proposition of the agricultural sector must also be resurrected in order to develop its human resources and draw in younger workers. Ensuring local value capture so that input suppliers, producers, and processors are able to enjoy livable profit margins will be key to continued poverty reduction in Indonesia's rural areas.

2. Though Indonesia has made great strides in reducing poverty, income inequality has grown between 1998 and 2018. Agriculture employs nearly a third of the population and 93% of Indonesian producers are small family enterprises. 64% of poor rural households engage in agricultural production. Large plantations producing export crops constitute a small portion of land area but generate an outsized share of agricultural value.

3. In coming decades, slow-onset climate shifts will decrease the crop suitability of several production systems key to poverty reduction and food security, such as rice and maize. Agricultural producers are also vulnerable to increasingly severe abiotic stresses such as rising temperatures, shifting rainfall patterns, drought, and flooding. Pest and disease outbreaks, often induced by higher temperatures, are also getting worse. Programmes to increase the climate resilience of small scale producers and value chain actors are critical to growing income and guaranteeing Indonesian food security.

4. Indonesia is the fifth largest greenhouse gas emitting country, with 61% of total emissions linked to forestry and 9% to agricultural production. Indonesia's REDD+ agreement with Norway may serve as a model for future results-based-payment schemes to incentivise conservation-minded policy making. Funds must also reach producers directly to assist them in pivoting to more sustainable production systems. Overall, more must be done to protect Indonesia's globally important forest, peatland resources, and biodiversity.

5. To ensure producers are able to adapt to these environmental risks, additional research and development, agricultural extension services, and information and advisory services are required

at both the national and local levels. CSA practices and technologies such as promoting the use of improved crop varieties and livestock breeds, conservation agriculture, water use efficiency, social forestry, integrated pest management, and digital advisory services–among others–will be key to successful development initiatives. Additionally, business development training for small scale producers, the development of producer groups, and innovative financing mechanisms to connect small scale producers with financial capital are needed.

6. In East Java, the System of Rice Intensification (SRI) can be combined with customary local cultural practices to conserve resources and increase production. Higher-value vegetable production can be achieved through strengthened information and advisory services, the provision of cold storage post-harvest infrastructure, and improved market access.

7. In North Sumatra, cattle and small ruminants can be integrated with oil palm farming systems to reduce inputs and cycle resources. Arabica coffee is another locally-important commodity, the value chain of which can be strengthened with higher quality inputs, enhanced local processing capacity, the development of producer groups, and improved connections with large buyers.

8. In Nusa Tenggara Timur, small producers should be assisted in diversifying production away from maize and toward more drought-tolerant and locally suited crops. Pig production systems can be scaled up with a high-value breeding programme, the upgrading of pig pens to minimize disease transmission, and enhanced agricultural insurance mechanisms to protect from losses.

9. These initiatives will require funding from multilateral, bilateral, domestic, and private sector financiers. Global development funds are required to underwrite ambitious domestic spending programmes that may not have direct return-on-investment, while the Government of Indonesia must support private sector firms and commercial finance institutions to invest in the agricultural sector by writing off some of the risks involved.

Introduction

Climate-smart agriculture (CSA) is agriculture that has been transformed and reoriented to support development and ensure food security in the face of climate change. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and farmers' income, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions in line with national development priorities. The CSA approach can help to identify synergies and balance trade-offs involved in pursuing these objectives by addressing food and nutrition security and the environmental, social, and economic dimensions of sustainable development across agricultural landscapes. This approach helps to align the needs and priorities of different stakeholders to achieve more resilient, equitable, and sustainable food systems.

While many CSA practices and technologies are new and innovative, even more are traditional and may already be in use. Scaling and mainstreaming CSA will require the systematic identification of locally effective CSA practices, diagnosis of barriers to adoption of those practices, evaluation of strategies to overcome the barriers, and ensuring the presence of institutional and financial enablers.

This CSA Country Profile describes the risks posed by climate change to agriculture in Indonesia, discusses the potential of CSA to attenuate those risks, identifies factors that can influence the adoption of CSA practices, and highlights potential entry points for investment in CSA at scale. The report is split into two parts; the National Profile and Provincial Profiles.

In the National Profile, agriculture's relation to economic development, livelihoods, specific social groups, land use, food security, and greenhouse gas emissions are explored, in addition to agricultural production systems critical to national food security and livelihoods. A series of quantitative analyses are then used to, firstly, project the impact of climate change on the suitability of key crops through 2050 and the effect this will have on yields and planted areas, and, secondly, the economic and trade implications these changes will have. Systemic challenges to the agricultural sector are then explored, alongside domestic policies and institutions related to CSA, the current CSA financing landscape, and opportunities for further funding and investment opportunities.

In the Provincial Profiles, qualitative research is employed to delve deeper into farming systems and agricultural value chains across three Indonesian Provinces (East Java, North Sumatra, and Nusa Tenggara Timur). Workshops related to farming systems are used to examine on-farm constraints to productivity and the farm-level impacts of environmental hazards, while separate workshops with value chain actors help identify how environmental hazards impact livelihoods linked to key agricultural production systems. CSA Intervention Packages are then formed from the priorities of small producers and agricultural value chain actors, and validated through key informant interviews. Ultimately, the Provincial Profiles are meant to serve as the evidence-base for further research and, potentially, future investment into specific CSA initiatives throughout Indonesia.

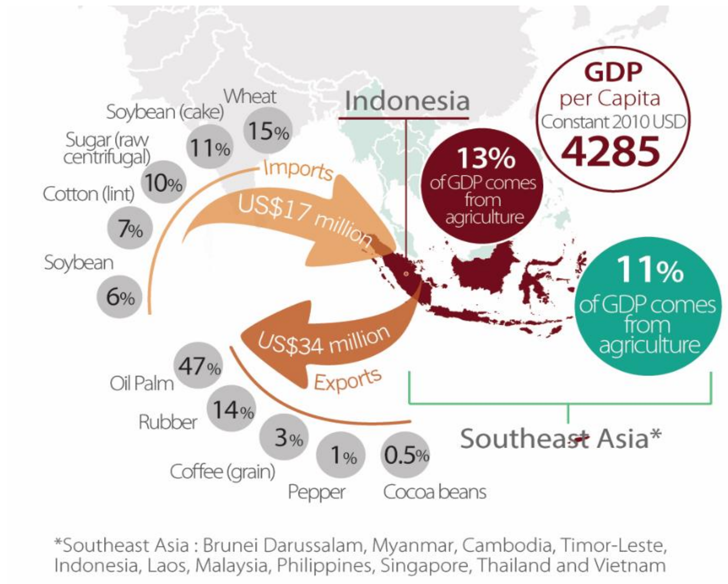
National Context

Economic relevance of agriculture

Indonesia's gross domestic product (GDP) per capita has grown steadily year-on-year since 2000, more than doubling from US $2,144 to US $4,285 in 2018 [1]. Its economy is the largest in Southeast Asia and, in 2017, was the tenth largest globally in terms of purchasing power parity [2]. While the share of agriculture's contribution to Indonesian GDP has declined to 13.5% of GDP in 2016, mainly to the benefit of the service sector, this is typical of the structural economic transformation associated with becoming a middle-income country, and the agricultural sector has still doubled in value since 2000, to US $79.2 billion in 2016 [3,4]. The value of agricultural exports grew by 526% between 2000 and 2010, when growth began to slow down and, between 2012 and 2016, reversed; export value grew by just 18% between 2000 and

2018 [5]. High value estate crops like oil palm, rubber, and coffee comprise a majority of agricultural exports while wheat, a cereal grain crucial for nutrition that Indonesia is ill-suited to produce domestically, soybean, which is used to produce local staple foods like tofu and tempeh, and sugar are key agricultural imports [6,7].

Economic relevance of agriculture in Indonesia



GDP per capita: [8]
IN Agricultural GDP: [4]
SEA Agricultural GDP: [9]
Value of Agricultural Imports and Exports: [5]

People, agriculture, and livelihoods

Agricultural growth played a key role in Indonesia's ascension to lower-middle income status in 2009, and continues to provide livelihoods and sustenance for a significant part of the world's fourth largest national population. The world's largest archipelago, Indonesia accounts for more than 40% of the Association of Southeast Asian Nations' (ASEAN) populace [10,11]. Employing 32% of the total labour force, agriculture is the second largest employment sector in Indonesia [12]. Though agriculture's share of total employment has dropped steadily, from 44% in 2005 to 30% in 2019, the sector still employs a large number of Indonesia's 268 citizens–its 117 million rural residents in particular [13]. The average small family farm in Indonesia has a diversified livelihood strategy, with on-farm production delivering just 49% of their total annual income–one of the lowest levels in Asia [12]. 93% of all agricultural producers in Indonesia are small-hold family operations comprising an average of 6 hectares, with 68% of smallholders operating on less than one hectare of land [12,14]. 64% of poor rural households engage in agricultural production [15]. Large plantations producing export crops constitute just 15% of agricultural land area but generate an outsized share of agricultural value [14].

While Indonesia's poverty rates are low for the region and represent the significant progress that has been made in reducing deprivation, Indonesia's large population means the number of poor households is still significant. The percentage of Indonesians living on less than $5.50 per day decreased from 30.9% in 2013 to 22.7% in 2017 [16]. Those living on less than US $3.20 per day decreased from 11.3% to 7.1% over the same period [17]. Between 2012 and 2017 alone, Indonesia reduced multidimensional poverty nationally by 12.2% per year, with more than half of its 34 provinces halving multidimensional poverty locally [18].

However, income inequality increased between 1998 and 2018, and while 7% of urban poor were impoverished in 2018, that number was 13.2% in rural areas where the majority of workers are employed in low-productivity, agricultural livelihoods [19]. Overall, progress has been uneven and pockets of scarcity remain; poverty rates in Papua and West Papua are twice the national average and most of the 32% of the population who lack access to basic services live in rural areas [20].

People, agriculture and livelihoods in Indonesia

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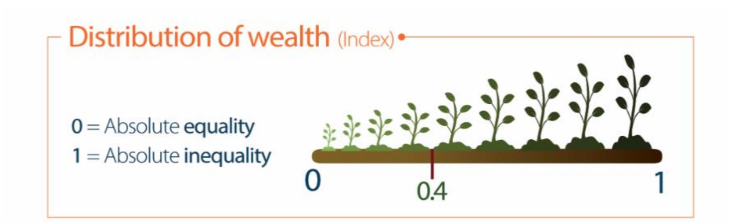

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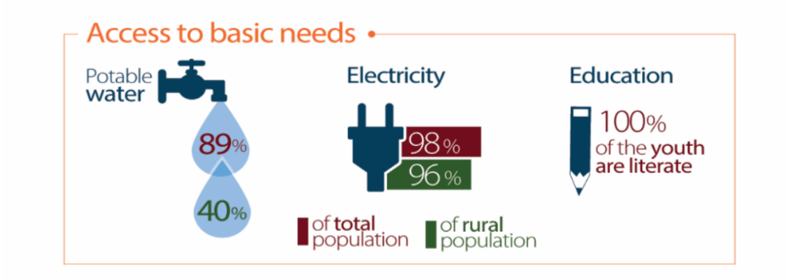
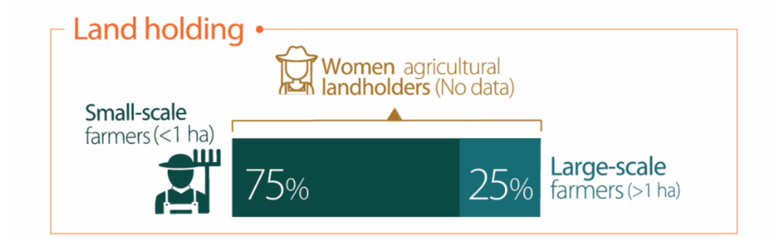


Water: [22]
Electricity: [23]
Literacy: [24]

US $3.20 / day:[25]
US $1.90 / day: [26]
National: [27]
Rural: [28]



[29]

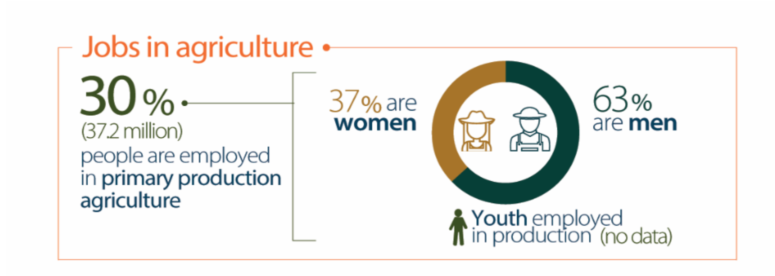
Value added per worker, Indonesia: [30]
Value added per worker, SEA: [31]
Value added per worker, OECD: [32]

Women and Youth in Agriculture

Though women play a significant role in Indonesia's agricultural production systems, they generally have less control over economic and productive resources, limited access to financial services and credit, are paid less than their male counterparts, and shoulder a greater burden of domestic work in addition to their agricultural responsibilities [33]. Agriculture employs 28.5% of Indonesia's female labour force, which is a larger portion than the industrial sector (16.5%) but nearly half that of the services sector (55.0%) [34]. While women comprise 37% of the agricultural workforce, they earn an average of 44% less than their male counterparts, just 13% of agricultural landowners are female, and only 11% of smallholder farms are female-headed [35,36,37]. Female decision-making power tends to be weakest at the household and village levels, while women hold an average of 19% of seats in Indonesia's national and regional parliaments [33]. Indonesia ranks 108th out of 187 countries on the Gender Inequality Index [38].

Women are typically expected to support agricultural activities on their parents' farm until they're married, at which point they do the same on their husbands' [33]. Women spend an average of 5.4 hours on agricultural production per day while also performing significant domestic labour around their time in the fields. Activities often overseen by women include seed preparation, crop planting, fertilizer application, weeding, harvesting, and many aspects of livestock production, including the cleaning of enclosures, feeding, and general animal care [33]. While men and women are both highly involved in agricultural labour, land preparation and the care of large animals like cattle, bison, and horses are typically performed by men [33].

The average age of an Indonesian farmer is 52 years old, and Indonesia's youth are increasingly disinterested in pursuing futures in the agricultural sector. Discouraged by a lack of access to land and income instability, many rural youths are moving to cities [39]. In Central Java, for example, just 4% of children from agricultural households will carry forward the family business [39]. Youth are increasingly absent from agricultural value chains, which contributes to chronic labour shortages that get worse over time (see *Challenges to the Agricultural Sector*). Indonesia has experienced urbanization typical of the region, with its rural population declining from 47.4% of total in 2014 to 44.7% in 2018. Between 2000 and 2015, the population of Indonesia's urban areas grew by 50 million, while rural areas shrunk by 5 million [40]. For men, the primary motivation of rural-urban migration is to pursue livelihood opportunities, and for women it is to follow their husbands [33]. The access to improved education and livelihood opportunities on offer in urban areas are a stronger magnet for male migration than the prospect of land inheritance and ownership in rural areas [33]. This indicates a growing labour crisis for smallholder farming and the need for robust interventions aimed at promoting entrepreneurship and rebuilding agriculture's value proposition.



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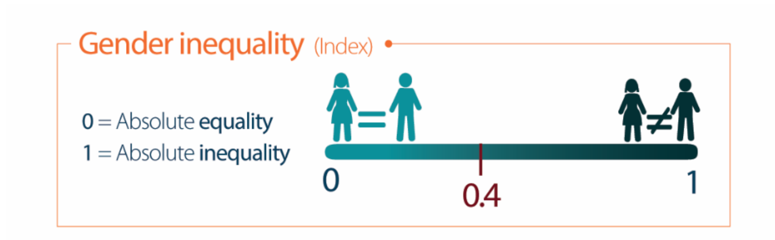


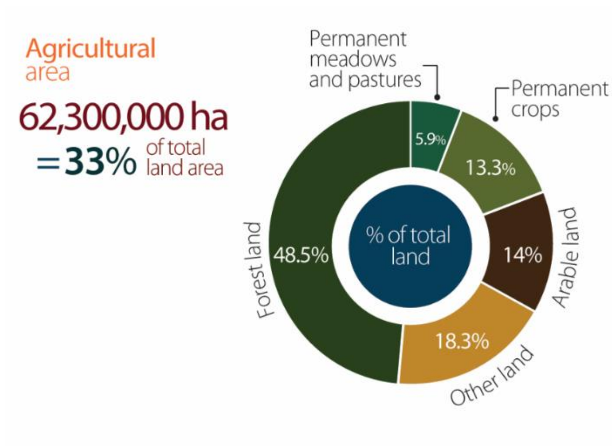
[41]

Land use

Indonesia is the world's largest archipelago, consisting of more than 17,000 islands and 42% of the ASEAN regional land cover [42]. Just under half of all land is forested and biodiverse, as Indonesia is home to 10% of the world's tropical rainforests, which are critical for above-ground carbon sequestration, 17% of earth's wildlife, and more than 800 endemic species [43,44]. Agricultural land comprises 33% of Indonesia's 192m ha of total land area, increasing by 1.7% between 2014 and 2018, while the percentage of forest land decreased at nearly the same rate over the same period [45]. This rate of agricultural expansion exceeds the regional average of 1.2% and is the second-highest in Southeast Asia after Vietnam [45]. With the portion of agricultural land equipped for irrigation declining by 1% from 2013 to 2017, and averaging just 11.5% of total agricultural land area over the same period, the great majority of Indonesian agriculture is rainfed [46]. Only 17% of land area equipped for irrigation is actually irrigated and the Ministry of Public Works and Housing estimates that just 55% of Indonesia's irrigation systems are fully operational, limiting general productivity and the growth of high-value commercial farming [47,48].

Despite slowing down since 2016, Indonesia has the fifth highest rate of deforestation in the world, having lost 9.3 million ha equivalent to 10% of its total tree cover between 2001 and 2018 [49]. This loss account for 7% of all global losses over the same period and are largely driven by an enormous increase in oil palm cultivation since 2000, which has seen Indonesia become the leading producer of oil palm globally at the cost of decreasing forest cover, a loss of biodiversity, and increasing greenhouse gas (GHG) emissions [50,51,52]. Oil palm cultivation has also expanded into Indonesia's tropical peatlands, which are swamps and swampy forests rich in partially decayed organic matter [53]. Despite covering just 3-5% of the earth's surface, peatlands hold more than 30% of the earth's terrestrial carbon [54]. When they are drained and cultivated, their potential for future carbon sequestration is eliminated and the carbon stocks already held in peatlands are released into the atmosphere. Despite efforts by the government to restrict peatland encroachment, Indonesia's 22.5 million ha of peatland is under increasing pressure from industrial agricultural encroachment.

Land use in Indonesia



[45]

Agricultural production systems

Indonesia's wide and varied topography hosts five distinct agroecological zones (AEZ): dry land and dry climate, dry land and wet climate, highland, lowland irrigation, and tidal swamp [55]. Sumatra, Java, Bali, Kalimantan, Sulawesi and Papua are all characterized by high elevations and forest cover, while Kalimantan is home to the largest area of peatlands, and Papua the largest concentration of both tropical forest and mineral deposits. Active volcanoes are present on Maluku, Nusa Tenggara, Sulawesi, Sumatra, Papua, Java, Bali and Kalimantan [56].

This diverse geography enables a wide variety of agricultural production systems, the highest value being paddy rice, palm oil, palm kernel oil, chicken, chicken eggs, maize, and cattle [3]. It is among the world's leading producers of estate crops such as rubber, coffee, cocoa, and coconut, as well as the second largest marine fisheries producer globally, with aquaculture contributing 2.3% to total GDP [57]. Indonesia is a net exporter of agricultural products, with exports totaling US $39.4 billion, and imports at US $19.5 billion in 2017 [5]. While the value of each of these commodities increased during the same period, palm oil and rice grew most steadily with a compound annual growth rate of 2.39% and 2.28% between 2010 and 2017 [59,60]. Despite the importance of agriculture to Indonesian communities, yields for eight of its twelve key production systems trail those of its regional neighbours [58].

Oil palm is Indonesia's largest production system and primary cash crop, with oil palm fruit and the tree itself generating 26% of the country's agricultural production value on 8% of total cultivated area [3]. 60% of oil palm plantations are located in Sumatra, 30% in Kalimantan, 3% in Sulawesi, and 7% spread throughout other provinces [59]. Approximately 6.8m ha are small and medium-sized plantations that are integrated into global supply chains, 4.8m ha are cultivated by independent smallholders, and 0.8m ha are state-owned plantations [60].

While the oil palm sector was historically overseen by the Ministry of Transmigration, as a livelihood strategy for resettled families who had moved to rural areas to ease "overpopulation," production began to increase exponentially through the 1980s and 1990s as private companies poured into the sector, which produced 45% of oil palm products (palm oil, palm kernel cake, and palm kernel oil) globally [58,61]. Driven by demand from large multinational food, cosmetic, and fuel corporations, production is highly advanced and dominated by large domestic and international agribusinesses, though state-owned producers and approximately 2 million smallholder farmers also cultivate oil palm on a total of 7.4 million ha (average 2014 - 2018) [58,62]. Productivity exceeds the regional average, at 1.7 tonnes per hectare (t/ha) [59]. Despite being used domestically as a cooking oil and a biofuel, the majority of oil palm is exported. Its relatively low cost to produce, environmental resilience, and high yields make oil palm an attractive production system; since 2000, the value of Indonesian oil palm production has increased by an average of 9% annually, to a total of $20.3B in 2016 [3,63]. Though the value of oil palm exports grew by 458% between 2003 and 2010, growth slowed down to 37% between 2010 and 2017 [5].

Despite the economic benefits of oil palm production, its production is devastating for both local ecosystems and global GHG emissions. Much of the forest being converted for oil palm is peat swamp, which is a carbon sink and thus plays an outsized role in global carbon sequestration. Much of this land area is classed as reclaimed rather than converted peatland, which means the peat has been modified to be productive, often through the creation of water canals, soil amelioration, and the addition of organic matter and fertilizers. However, there is skepticism within the scientific community as to whether one portion of a peat swamp can be conserved while another is rendered productive, or whether a production in one area will have negative knock-on effects throughout the local ecosystem (see *Policies and Institutions for CSA*) [66]. Slash-and-burn and oil palm mono-cropping also have negative effects on local biodiversity, which is of critical concern as Indonesia is home to a significant number of species that are endemic to vulnerable forestland. Though orangutans and tigers have become oil palm's most visible victims, in the past forty years Indonesia's wildlife populations have decreased at twice the rate of any other country, largely due to oil palm-driven habitat loss [67]. Indonesia's state auditor, BPK, recently found 19% of palm oil plantations to either be fully illegal or operating in violation of recently introduced and legally-binding Sustainable Palm Oil standards, which are meant to mitigate the industry's harshest effects [68].

Indonesia is the third largest producer of rice globally, behind only China and India [60]. While rice was historically Indonesia's primary production system, it was overtaken in terms of value by oil palm in 2010 but remains the country's most important staple crop. Rice consists of 15% of total harvested areas with yields averaging 5.2 t/ha between 2015 and 2019 [60]. These are the highest yields in Southeast Asia, after Vietnam, and exceed the regional average of 3.8 t/ha by 36% [58]. In 2018, nearly all of Indonesia's 81 Mt of rice were for domestic consumption, as Indonesia exported less than 1% of its rice and imported an average of 751,000 tonnes of additional rice from international markets annually between 2013 and 2017 [5,59]. Rice is critical to Indonesia's food security, and 87% of poor households purchase additional rice for consumption in order to supplement what they grow [64].

Rice is typically grown on the islands of Java (largest producer), followed by Sumatra, and Sulawesi, which together comprise just under 90% of total national production [65]. Though upland rainfed systems and lowland irrigated systems are both well represented, lowland systems tend to be heavily fertilized and can support three crops per year, and as a result account for 80% of Indonesia's rice growing area and 93% of total production, with 60% larger yields than upland areas [65]. Indonesia's main rice growing season for both rainfed and irrigated systems occurs at the onset of the rainy season around October and November, with harvesting taking place at the season's close in April [65]. Irrigated systems can support two additional seasonal crops between May and August, and September and December [65].

Livestock production also plays an integral role in Indonesia's agricultural sector. Chicken (meat and eggs in shell) comprises 9.8% of total agricultural production by value, while cattle (meat and milk) make up 3.1%, pig 0.7%, and goat (meat and milk) 0.5% [3]. Java has the largest average population of beef cattle, buffalo, dairy cattle, goat, sheep and broiler chicken, followed by Sumatra, while Nusa Tenggara Timur has the largest population of pigs [66]. Despite the size of these production systems, value lags behind volume as productivity in the livestock sector is generally poor, with yields substantially lower than the regional average: 33% lower for goat, 35% lower for chicken, 57% lower for sheep, and 64% lower for pig [67]. Cattle yields, however, exceed the regional average by 25% [67]. The Indonesian poultry industry employs 10% of the national labour force and provides 65% of all animal protein in the national diet [68]. Poultry production is centered in Java, where maize for feed and markets for retail are convenient to access [68]. Cattle production is concentrated on Java and the Eastern Islands. Beef is a traditional part of Indonesian diets, and increasing domestic demand and high-value export opportunities have driven production up in recent years [69].

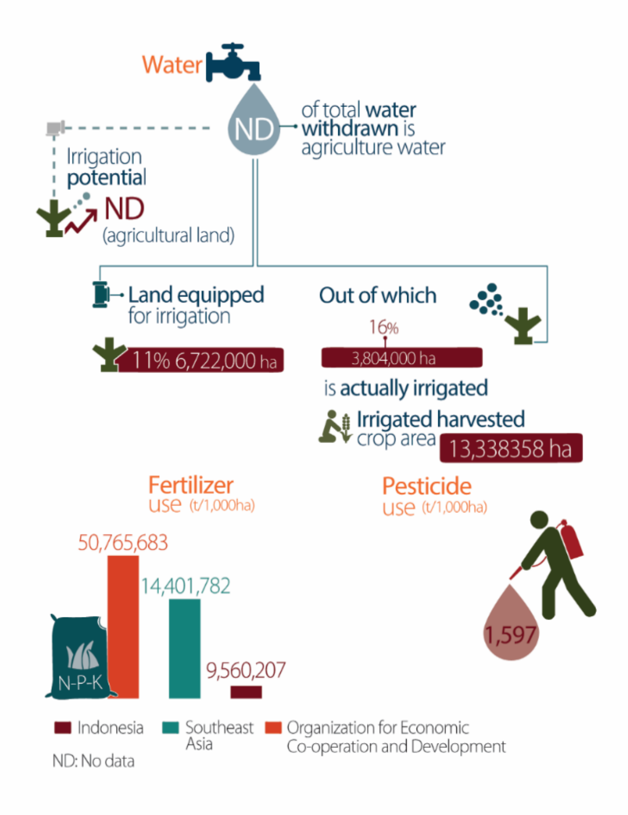
The Government of Indonesia (GoI) has invested heavily in growing fertilizer use through subsidies and the regulation of retail price ceilings since 1969, though investment levels have increased markedly since 2007 [19,70]. Additionally, subsidies may encourage excess application that results in runoff and pollution [20]. However, despite subsidization, Indonesia's fertilizer use is 51% lower than the regional average [58,71].

From 1989-1999, Indonesia's National Integrated Pest Management Program was largely successful in reducing pest infestations through a participatory, community-driven approach to ecosystem health in which local knowledge was shared through a network of farmer field schools [72]. However, the *Reformasi* political reforms and democratic decentralization drives of the 2000s ushered in a more market-driven approach, in which the gap left by the National Integrated Pest Management Program was filled by an ever-growing number of pesticide brands being aggressively marketed to farmers [72]. This has led to overuse of pesticides and a resurgent of pests that had previously been successfully managed, such as the brown planthopper, which has savaged rice crops [72]. Additionally, pesticides are highly toxic and have had an adverse effect on the physical health of farmers that use them, and the ecosystems to which they are applied [72,73].

Production Systems Key for Food Security in Indonesia

[58]

Agricultural input use in Indonesia



Land equipped for irrigation: [45]
Land actually irrigated: [45]
Irrigated harvest crop area: [48]

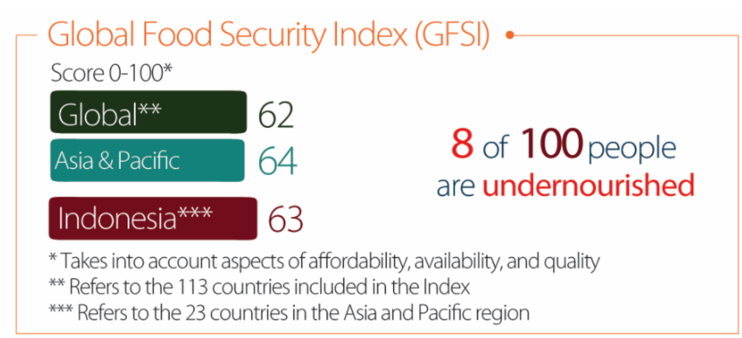
Food security, nutrition and health

Despite Indonesia meeting its MDG to halve malnourishment by 2015, food security remains a persistent challenge [2]. About 19.4 million people are unable to meet their dietary requirements, an alarming 36% of children in all economic classes face stunted growth due to malnutrition, 10% of children are wasted, and 58 of 398 rural districts are considered highly vulnerable to food insecurity [2,74]. With a score of 62.6, Indonesia ranks 62nd out of 113 nations on the Global Food Security Index [75].

Indonesia's basic challenge of producing sufficient food to feed such a large population is exacerbated by poverty, inequality, and policy-induced economic stresses. Government policies intended to generate food security through agricultural self-sufficiency have put pressure on domestic supply chains, while import barriers have pushed food prices 50-70% higher than in neighbouring countries, rendering nutritious foods unaffordable to many poor and middle-class Indonesians [64]. As a result, the average Indonesian spends two-thirds of their personal income and half of their household income on food [2]. Though government spending on agriculture has increased significantly and social protection programs are in place to help the most vulnerable (see *Policies and Institutions for CSA*), these measures often fail to deliver the quantity and variety of foods necessary for proper nutrition, and micronutrient deficiencies remain endemic [64]. Diets are generally over-reliant on rice and lack sufficient protein for physical and cognitive development, while the overconsumption of highly caloric foods with little nutritional value has led to the "double burden" of simultaneously increasing rates of undernutrition and obesity [76].

Despite meeting its MDG to provide improved water supplies to 87% of its population, a lack of clean water for drinking, washing, and agricultural productivity remains a major driver of illness and poor sanitation in Indonesia [77]. Indonesia lacks the reservoir capacity to match its population; this is particularly pronounced in Java, which is home to more than 50% of Indonesia's population but possesses less than 10% of its water resources [64]. Just under 40% of Indonesia's rural population have access to potable drinking water [22]. Under threat from increasing temperatures, changing rainfall patterns, and increased flooding, dam storage capacities have fallen 93% short of the targets set out in Indonesia's 2005-2025 National Long-Term Development Plan [78]. Strict laws meant to protect waterways from industrial pollution are unevenly enforced, and a lack of sanitation and waste water treatment capacity, particularly in rural areas, renders surface water dangerous [64]. Deforestation has diminished a natural check against flooding, reduced a source of natural water filtration, and increased the exposure of rural and coastal communities to natural disasters, which occur with increasing frequency [78,79].

Food security, nutrition and health in Indonesia



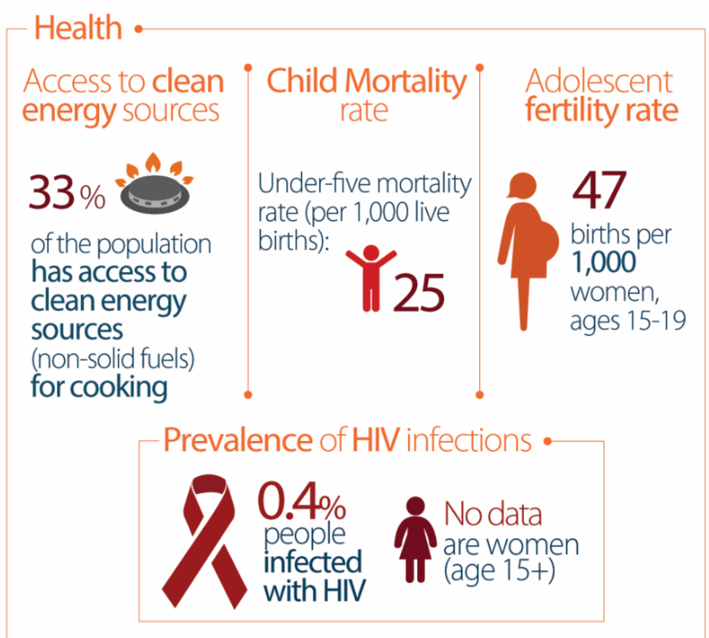
Food security index: [75]
Undernourishment: [80]

Per capita food production variability: [22]

Calories available, crops: [81]

Calories available, livestock: [82]

Children wasted: [22]



Energy: [83]
Child mortality: [84]
Adolescent fertility: [85]
HIV: [86]

Agricultural greenhouse gas emissions

Indonesia is the fifth largest emitter of greenhouse gas (GHG) emissions globally, with 61% of its total emissions stemming from land-use change and forestry and 9% from agriculture [87,88]. Its total emissions exceed that of even its highly industrialised East Asian neighbours Japan, South Korea, and Australia, but are lower than each on a per capita basis [89]. Between 2000 and 2017, Indonesia's total GHG emissions increased steadily, rising by 62%, from 1.4 to 2.3 gigatonnes of carbon equivalent (Gt CO_2e), which is faster than both the global rate of 33% and the regional rate of 51% over the same period [90]. Between 2000 and 2017, Indonesia's agricultural GHG emissions exceeded the regional average of 1.7%[1] to grow by an average of 2.6% per year [91].

Land use change and forestry is Indonesia's largest source of GHG emissions, accounting for 59.7% of the national total in 2017 [88]. Within the land use sector, forest land accounts for 73% of emissions, and cropland another 22% [92]. The cultivation of oil palm, while an economic boon, is also a key driver of emissions as forests are cleared and peatlands drained to expand production. In addition to limiting future

[1] Singapore has been excepted from this average as it, at 50.7%, is the only country in the region to have an average annual growth rate exceeding 3%.

carbon sequestration potential by removing aboveground biomass, when peat swamps are converted into crop land, large quantities of greenhouse gases already sequestered belowground are released; as a result, peatland oxidation caused by Indonesian palm oil cultivation accounts for 0.74% of *global* greenhouse gas emissions [93].—Due to significant economic incentives and climate-induced improvements in oil palm suitability, additional policy and institutional frameworks are required to mitigate the potential for environmental damage increased oil palm production poses over coming decades (see *Agricultural Production Systems, Economic Impacts of Climate Change,* and *Recommended CCSA Intervention Package 3).* Additionally, land is often cleared with illegal slash-and-burn practices that produce large amounts of smoke. In 2015, fires set for peatland development spread out of control in Sumatra, Kalimantan and Papua; daily GHG emissions from these fires alone exceeded those of the entire United States, caused $16B in damage, and are forecast to lead to the premature deaths of 100,000 residents through smoke-induced acute respiratory illnesses [62].

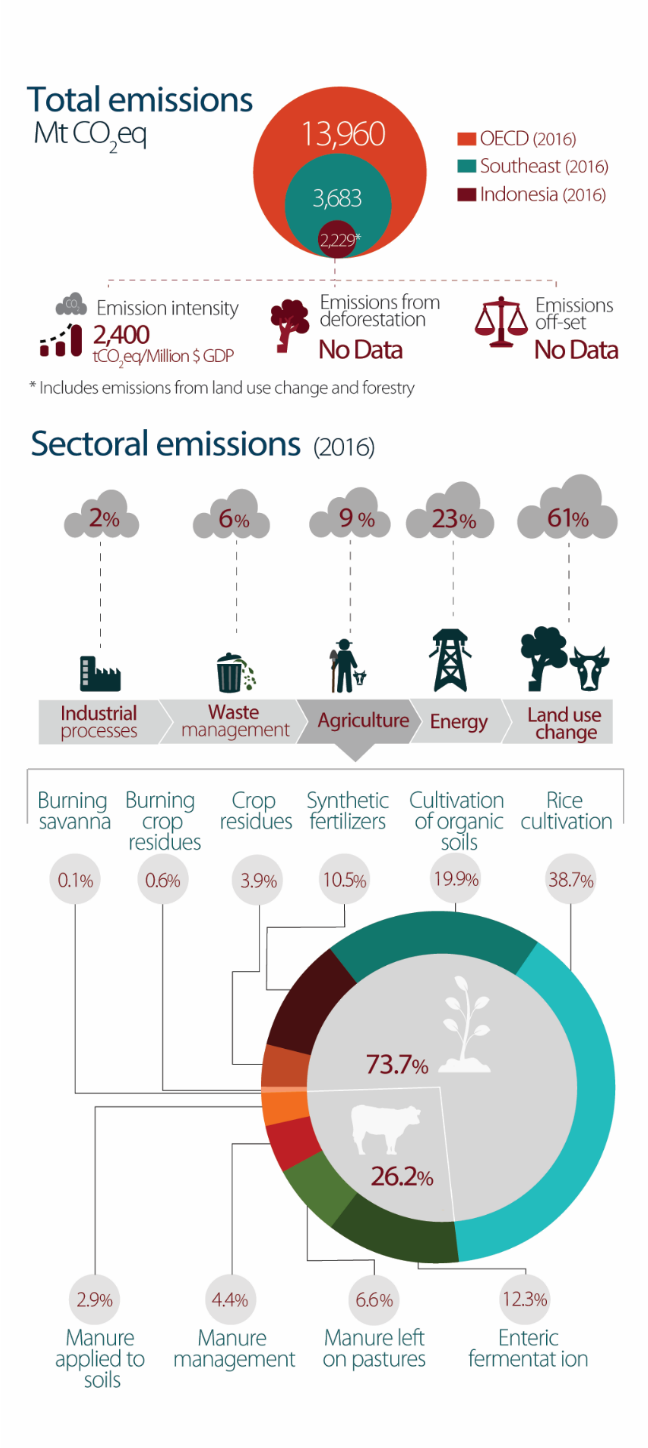
Indonesia's agricultural emissions account for 38% of the region's total[2] with 41% of the ASEAN population [31,91]. Rice cultivation is the largest source of emissions within Indonesia's agriculture sector (39%), followed by the cultivation of organic soils (20%), enteric fermentation (12%), and synthetic fertilizers (11%); the four sources combined comprise 82% of total agricultural emissions [91]. More than 99% of emissions from rice cultivation consist of methane produced by anaerobic fermentation driven by continuous flood irrigation [94].

Livestock emissions comprise 26% of Indonesia's agricultural emissions, with enteric fermentation accounting for 47% of the livestock total, along with manure left on pasture (25%), manure management (17%), and manure applied to soils (11%) [91], The production of beef cattle accounts for 71% of GHG emissions from enteric fermentation, followed by 11% from goats, 9% from sheep, 7% from buffalo, and 3% from dairy cows[3] [95].

Greenhouse gas emissions in Indonesia

[2] This regional metric includes Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Timor-Leste, and Vietnam.

[3] Based on a Tier 2 approach to calculating species-disaggregated livestock stocks from 2016.



Total emissions, Emissions intensity, Sectoral emissions: [96]
Agricultural emissions: [91]

Agriculture and climate change

Indonesia has a tropical climate with two main seasons: the wet season lasts from November-April, with rainfall that peaks in January and February, and the dry season from May-October, during which July through September are the driest months. Temperatures are fairly constant throughout the year with slight variations in average temperature across elevations; 28°C in the coastal plains, 26°C in the mountain areas and 23°C in high mountain areas. Rainfall ranges from 1200 mm - 3200 mm in the lowlands, and up to 6,000 mm in the mountainous areas [97]. Indonesia's climate is strongly influenced by the El Niño Southern Oscillation, which supplies both warm, dry El Niño years and cool, wet La Niña years [98].

Since 1985, surface temperatures have increased by an average of 0.04°C per decade, with a 0.64°C increase from 1960-2006 and a 0.76°C increase between 1985 and 2005. Climate change projections suggest likely temperature increases of approximately 0.4°C per decade going forward, contributing to an overall increase of 0.9-2.2°C by 2060 and 1.2-3.3°C by 2100 [97,99].

While a 12% increase in annual rainfall has been recorded between 1990 and 2020, projections indicate increasingly erratic rainfall patterns in coming years. While annual rainfall is estimated to increase at the national level by 1-5% by 2100, large variations per season are expected, including a 4.8% decrease in dry season rainfall [100]. By 2050 delayed onset of the annual monsoon season by up to thirty days 30-day would bring a 10% increase in rainfall toward the end of the wet season and beginning of the dry season (April-June) [101]. This would also result in a 75% decrease in rainfall later in the dry season (July-September) [101].

Bias-corrected climate projections derived from the CCAFS-Climate Statistically Downscaled Delta Method were used to explore projected changes in climate from the Coupled Model Intercomparison Project Phase 5 (CMIP5) [102]. A high-emissions RCP 8.5 scenario was chosen for the assessment as it is closest to the current global emissions trajectory, accounts for the inertia inherent in the global climate system, and represents the greatest challenge to mitigation and adaptation efforts. This "worst-case scenario" is also closest to our current reality and serves as a strong foundation on which to plan risk management actions.

Under a high emission scenario–Representative Concentration Pathway (RCP) 8.5)–temperatures are projected to increase by 1.5°C by 2050. Projected changes in annual mean temperatures and precipitation were modelled using an ensemble of 33 Global Climate Models (GCMs) [102]. The results show a nationwide temperature increase ranging from 1.4°C to 1.5°C, with the central regions of Kalimantan, Sumatra, Java, Sulawesi and Western New Guinea likely to experience a >1.7°C increase. Conversely, a smaller average increase of <1.4C is projected for the northern regions, including the Maluku islands and Northern Sulawesi.

Changes in annual precipitation will also vary regionally, with Western New Guinea and Central Kalimantan expected to experience the highest increases, of >4.5% and >5.7%, respectively. Indonesia's southern and western regions are expected to see decreased rainfall in coming decades, with a projected 1.7% decrease in Java and 0.5% decrease in the Lesser Sunda Islands.

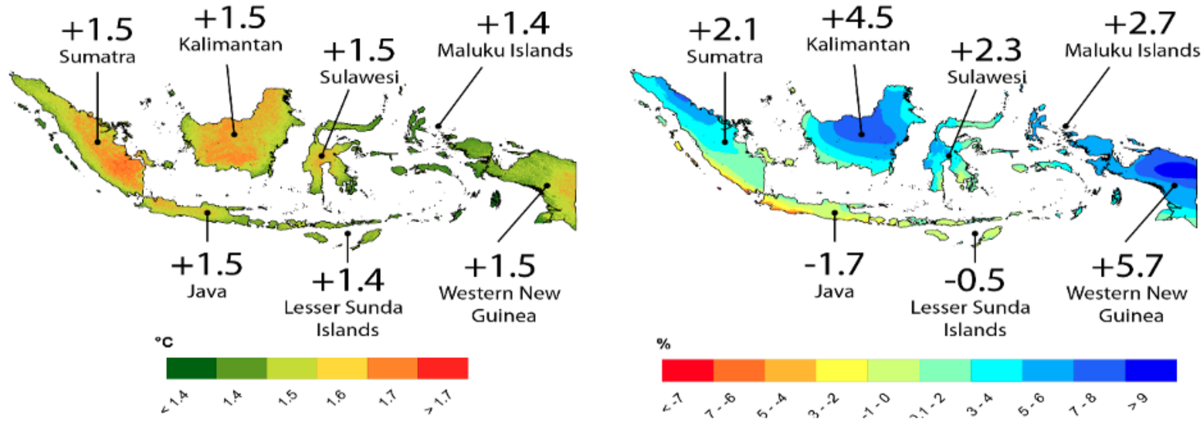
While the link between climate change and extreme weather is often opaque and indirect, Indonesia is highly vulnerable to natural disasters. Though many environmental hazards occur independent of climate change, others are made worse and occur more frequently under a changing climate. Heavier concentrations of rain are likely to exacerbate the impacts of flooding and landslides, while less frequent rains and a delayed monsoon season will worsen drought and forest fires [108]. Increased temperatures will help spread pests and diseases that harm humans, crops, and livestock [108]. Indonesia's capital, Jakarta, is in the process of being relocated due to the threat faced by sea level rise and its rate of sinking [108]. Natural disasters erode the long-term livelihood resilience and adaptive capacity of communities, leaving them more vulnerable to climate and non-climate related shocks while constraining national socio-economic development.

Nearly 23,000 extreme weather events occurred between 1998 and 2018, with flooding accounting for 39% of all instances, followed by heavy storms (26%), landslides (22%), drought (8%), and forest/bush fires (3%), along with tidal waves, earthquakes, tsunamis, and volcanic eruptions [103]. Indonesia is located in the Pacific Ring of Fire, where tectonic plates collide, causing volcanic eruptions, earthquakes, and tidal waves. In 2004, a 9.1 magnitude earthquake off the coast of North Sumatra triggered a tsunami that resulted in more than 230,000 deaths in 14 countries–including 170,000 in Indonesia [104].

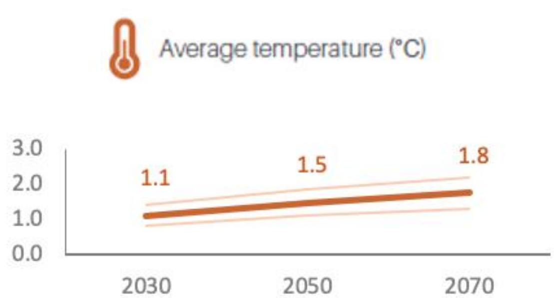
While this event is notable for its devastating magnitude, smaller hydro-meteorological events are a frequent occurrence; on average, Indonesia has experienced one major natural disaster per month since the 2004 tsunami [105]. Despite adopting the Hyogo Framework for Action, signing the Sendai Framework for Disaster Risk Reduction (DRR), and creating the National Disaster Management Agency (BNPB) and Provincial and District Disaster Management Agency (BPBD), Indonesia's early warning, social protection, and humanitarian relief systems are still lacking [106].

DRR and CSA go hand-in-hand and should be scaled in tandem, as CSA can play a significant role in building resilience [107]. Climate-change induced drought is likely to increase the frequency and severity of wildfires, and larger tropical cyclones are likely to cause significant damage and flooding [103]. Forest and peatland degradation is also linked with increased floods, landslide, and forest fires [108]. CSA measures that protect the natural environment can help mitigate these impacts, while those that increase adaptive capacity can build the resilience of vulnerable communities.

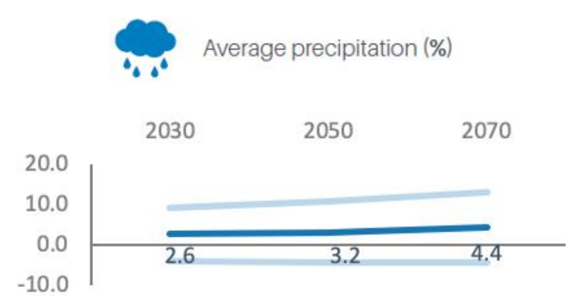
Projected changes in temperature and precipitation in Indonesia by 2050



Changes in annual mean temperature (°C)



Change in total precipitation (%)



Impacts of Climate Change on Crop Suitability

To assess the impacts of climate change, simulations of rice, maize, and oil palm suitability were performed using the EcoCrop model[4], which classifies suitability into five increasingly favourable categories: very marginal, marginal, suitable, very suitable, and excellent [109].

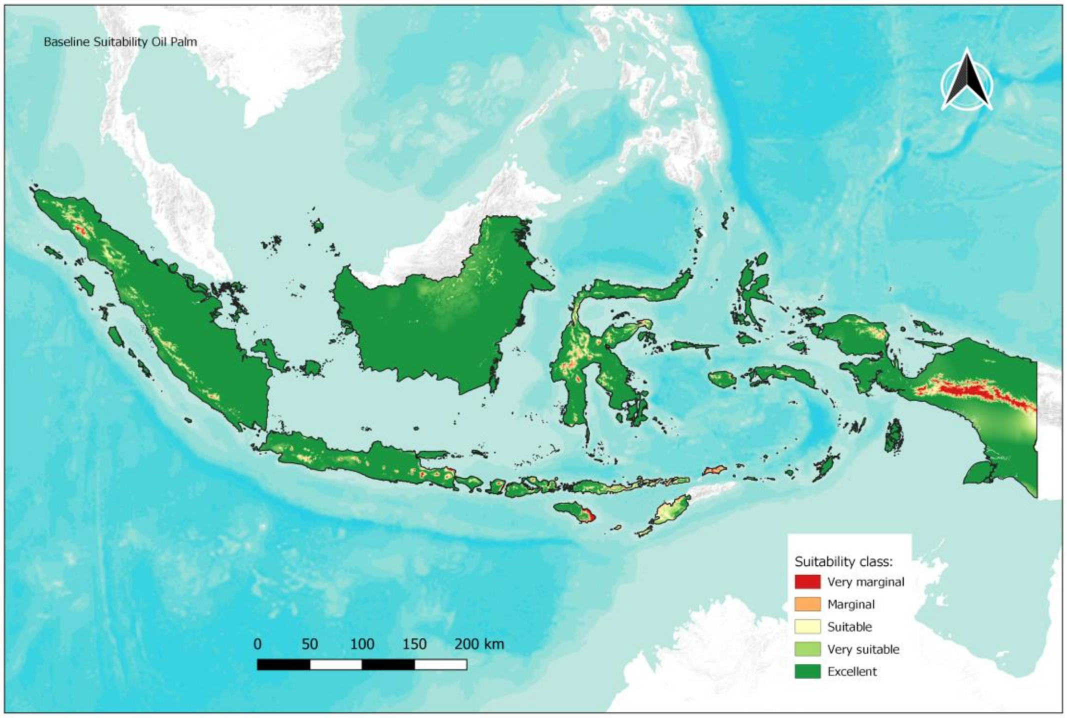
Projected oil palm suitability

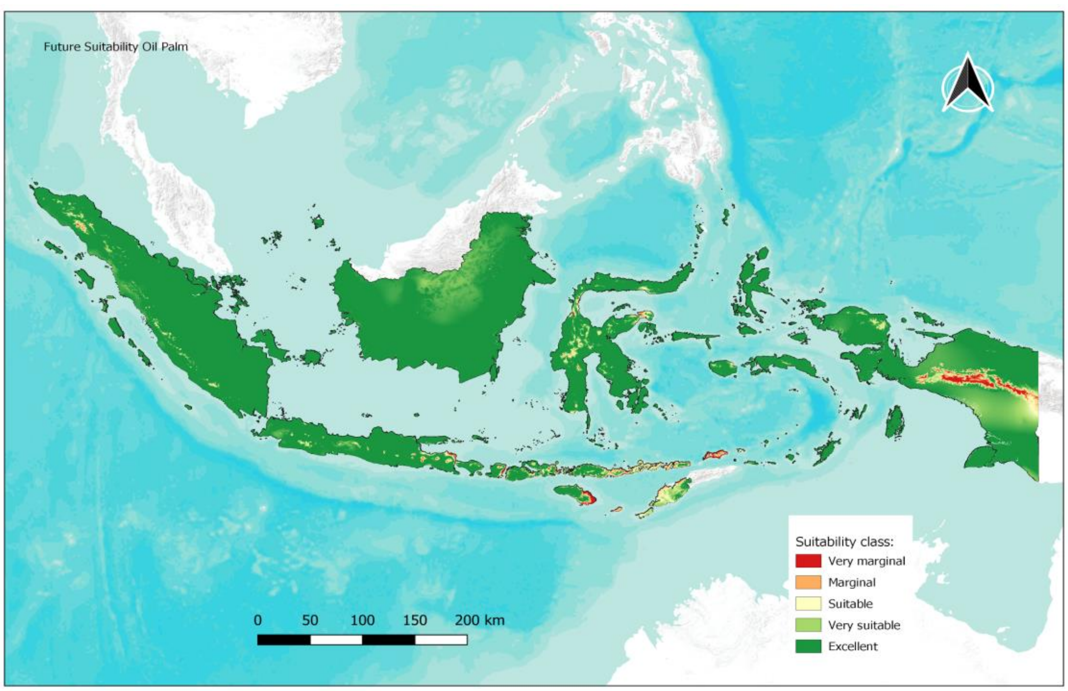
Crop suitability for oil palm will increase through 2050 across Indonesia, with many areas going from suitable to very suitable and Sumatra, Java and Kalimantan experiencing the greatest increases. Given the negative impacts that oil palm production has on carbon mitigation and biodiversity, this potential for increased production must be matched with new policies and increased investment toward CSA practices.

[4] EcoCrop is a simple process-based model that combines monthly means of maximum and minimum temperature with monthly precipitation totals to assess the degree of climate suitability for specific crops. The model uses crop-specific parameters that define the optimal and marginal seasonal temperature and precipitation conditions, and then compares these with local conditions at either current or future climate conditions.

Although most oil palm production takes place on land already under agricultural cultivation, policy frameworks and sustainable production models are required to prevent expanded cultivation on vulnerable land types (see *Economic Impacts of Climate Change* and *Recommended Provincial CSA Intervention Package 3)* [110].

Oil palm suitability in Indonesia for baseline and future scenarios (2050, RCP 8.5)

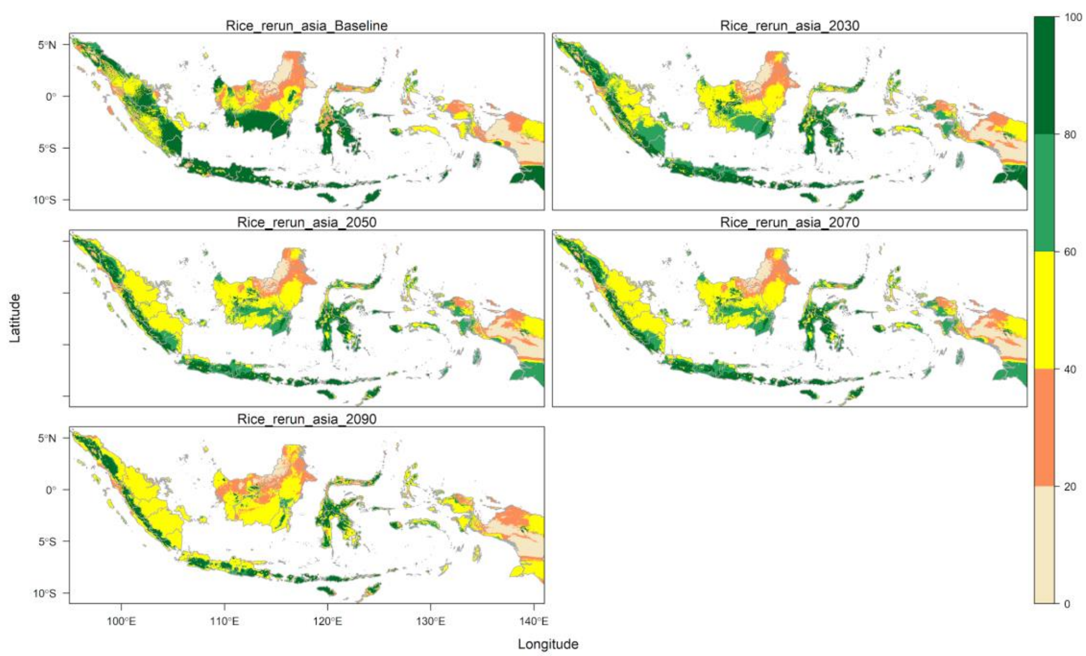




Projected rice suitability

The rice suitability simulation indicates a slight decrease in climate suitability from baseline historical data (1970-2020) through 2030 in the key rice producing areas of Java and Sumatra, with suitability decreasing from excellent to very suitable. Between 2050 and 2090 suitability will decrease further, particularly in the main rice -producing southern regions of Sumatra, Java and Sulawesi, which will go from being very suitable to suitable. Although production will still be possible, this shift has the potential to critically impact both food security, as Indonesia is a net-importer of rice, and livelihoods, as a majority of smallholder farmers rely on rice production for household income [12]. A 30-day delay to the onset of the rainy season will further delay planting and affect the number of annual crop cycles. This reduction in rainfall will diminish the growing season for rice. Water saving technologies and stress tolerant crop varieties should be introduced to offset the negative impacts of climate change agriculture in key production areas.

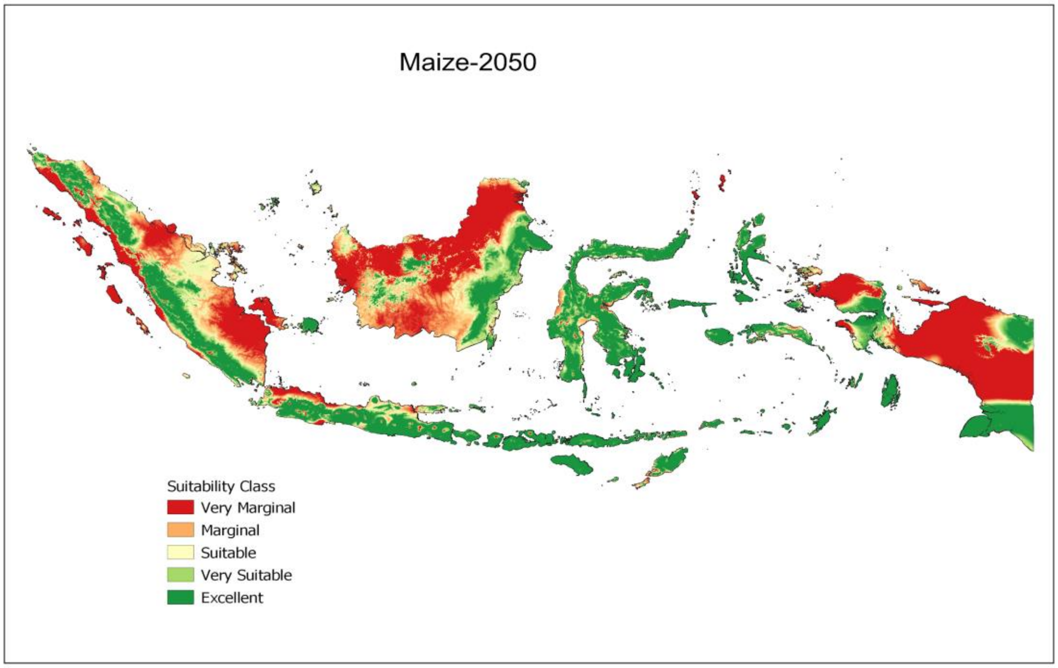
Rice suitability in Indonesia for historical and future scenarios (2030, 2050, 2070, 2090; RCP 8.5)

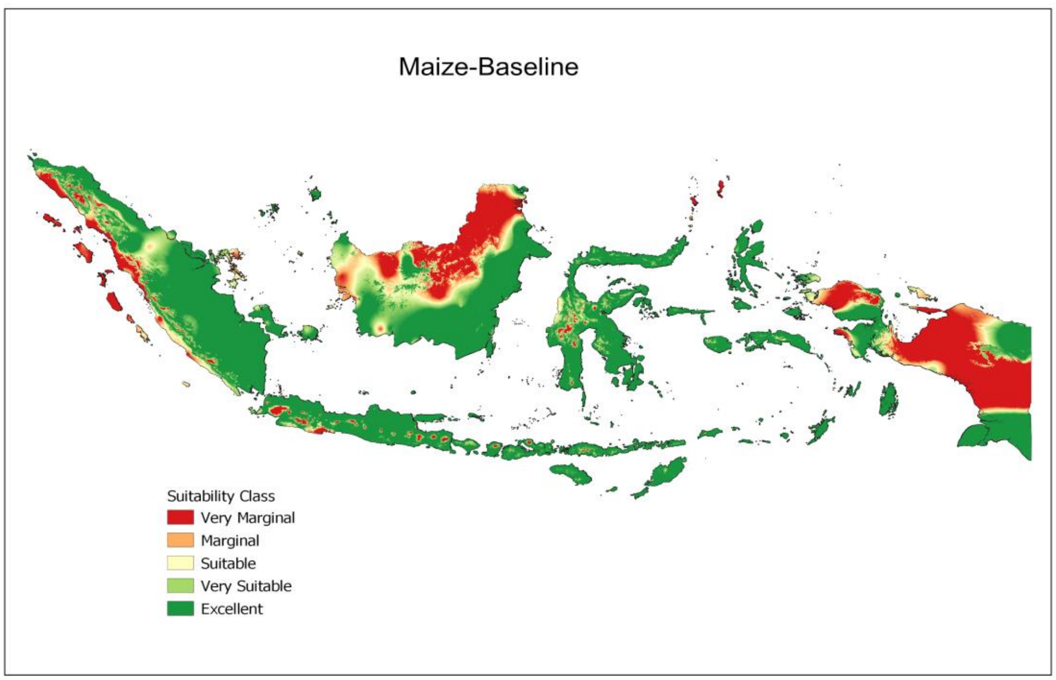


Projected maize suitability

Across Indonesia, the suitability of maize will decrease from marginal to very marginal by 2050. Shifting environmental conditions will most drastically decrease suitability in the regions of Java and Sumatra, and especially in the provinces of North Sumatra, Lampung, and West Java. As these are Indonesia's primary maize production areas, yields are expected to decline significantly in coming decades [111].

Maize suitability in Indonesia for baseline and future scenarios (2050, RCP 8.5)





Economic Impacts of Climate Change

To examine the impacts of climate change through 2050 on net trade, yield, production area (for crops), and animal numbers (for livestock), an analysis of Indonesia's key agricultural production systems was performed using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) [112]. IMPACT is a partial equilibrium model that uses a system of linear and nonlinear equations designed to estimate supply and demand relationships for key agricultural commodities on a global scale.

IMPACT results compare future climate and socioeconomic scenarios. Representative Concentration Pathways (RCPs) offer a set of different pathways representing the levels of atmospheric greenhouse gasses under alternative future emissions scenarios.

- RCP 4.5 represents a medium emissions scenario where radiative forcing (from atmospheric GHG concentrations) is at 4.5 watt per square metre (w/m^2) in the year 2100 without ever exceeding that value [113]

- RCP 8.5 represents a very high emissions scenario with atmospheric GHG concentrations that deliver 8.5 w/m^2 across the planet [113][5]

- NoCC data result from running the model with either an SSP2 or SSP3 scenario (see below) but without any climate change forcing. This is used to segregate the impacts of atmospheric change from those of social, economic, and political developments. NoCC includes atmospheric GHG concentrations that have occurred through 2020, but accounts for no additional emissions going forward, with atmospheric concentrations remaining constant at current levels.

- Current production levels are based on 2005 data run through the model to 2020 under a NoCC scenario and SSP2, considering NoCC is based on current atmospheric carbon concentrations.

Furthermore, two different socio-economic scenarios are considered in this analysis, represented by the Shared Socioeconomic Pathways (SSPs). SSPs are models that represent alternative futures of societal evolution as shaped by public policy and economic choices, taking into account socio-economic factors such as population, education, urbanization, and GDP, among others [114]. Agricultural variables accounted for in the SSPs include land-use change regulation, land-based mitigation policies, improvements in land productivity, the environmental impact of food consumption and dietary trends, international trade, and globalization [115]. Furthermore, the IMPACT model evaluates a number of technology scenarios based on the adoption rates of agricultural technologies consistent with sustainable

[5] As with the EcoCrop model, a high-emissions RCP 8.5 scenario was chosen for the IMPACT assessment as it is closest to the current global emissions trajectory, accounts for the inertia inherent in the global climate system, and represents the greatest challenge to mitigation and adaptation efforts. This "worst-case scenario" is also closest to our current reality and serves as a strong foundation on which to plan risk management actions.

intensification, such as no-till, integrated soil fertility management, drought- and heat-tolerant crop varieties, and improved irrigation technologies [112].

- SSP2 represents a "middle of the road" scenario where social, economic, and technological trends don't deviate from historical patterns. Challenges to climate change mitigation and adaptation are rated as medium [114]

- SSP3 represents a "rocky road" scenario where national policies are geared towards national security due to growing regional competition and conflict, as opposed to multilateral cooperation–i.e., low investment in education, technological development, and the environment. Challenges to climate change mitigation and adaptation are rated as high [114]

It is worth noting that all SSPs encompass large changes in demographics, human development, economy, institutions, technology, and the environment following existing global trends, with varying SSPs representing more granular variations in different narratives of future socio-economic development. This is why large changes in crop production and net trade parameters are seen across all RCP/SSP scenarios due to existing global trends, with smaller changes attributed to the specific scenarios. Results are generated by combining global development narratives with national-level data on population growth, educational attainment, urbanization levels, GDP growth, GDP per capita, and an economic inequality metric (Gini), before overlaying them with varying global mitigation scenarios (RCPs) [114].

Measuring Results

The IMPACT results are used here to assess the potential impact of different climate change and socio-economic scenarios on crop and livestock production parameters over future time periods. The in-text analysis below focuses on the percentage difference between (1) current production levels and (2) future production levels under a combined RCP 8.5 and SSP2 scenario, which are the business-as-usual scenarios considering historical GHG emissions and socio-economic trends. However, it is worth noting that should current commitments under the global climate policy framework be met, atmospheric GHG concentrations would likely be below RCP 8.5. Where the model projects large disparities in production levels between different RCP or SSP scenarios, it is flagged to indicate an apparent tipping point. IMPACT results may not align with those from the EcoCrop model as the latter is simply a biophysical suitability analysis, while the former accounts for a wider variety of economic and political variables in both the country in question and its trading partners, as well as that country's evolving comparative advantage.

The general relationship across different scenarios is that climate change will either positively or negatively impact a commodity's production indicators, with a greater variance experienced under RCP 8.5 (high emissions) than under RCP 4.5 (medium emissions). In general, a greater divergence is seen in production parameters when comparing different RCP scenarios than SSPs. A full breakdown of the different scenarios and their impact on yield, production area (for crops), and animal numbers (for livestock) can be seen in the tables below.

Results

This analysis indicates that climate change will have mixed effects on Indonesia's agricultural production, likely contributing to an increase in yields, land area, and suitability for some crops and livestock, and a decrease for others. The results suggest that, for the most part, Indonesia's key crops will experience increases in yield and production areas through 2050. The most significant influences on future production tend to be the global macro-factors accounted for in the SSP scenarios, which are the future vectors of already occurring social, economic, and political trends. While varying climate change scenarios either mitigate or amplify these effects, the RCPs are generally not the single most important factor of future yields, planted areas, or livestock populations.

Impact of various socio-economic and climate change scenarios on crop yields through 2050

Yield (tonnes/ha)

Commodity	Climate Scenario			
	SSP Scenario	NoCC	RCP4.5	RCP8.5
Rice	SSP2	28%	29%	30%
	SSP3	29%	29%	29%
Cacao	SSP2	28%	26%	26%
	SSP3	26%	25%	23%

Coffee	SSP2	34%	34%	35%
	SSP3	32%	32%	32%
Maize	SSP2	11%	0.36%	-5%
	SSP3	10%	-0.16%	-6%
Palm Fruit	SSP2	6%	6%	6%
	SSP3	5%	4%	3%

*Textual analysis based on SSP2 & RCP8.5 scenarios, unless otherwise stated.

Impact of various socio-economic and climate change scenarios on production area through 2050

Area ('000 ha)

Commodity	Climate Scenario			
	SSP Scenario	NoCC	RCP4.5	RCP8.5

Rice	SSP2	-3%	-2%	-1%
	SSP3	3%	5%	6%
Cacao	SSP2	9%	10%	9%
	SSP3	-2%	-2%	-2%
Coffee	SSP2	10%	11%	11%
	SSP3	8%	9%	9%
Maize	SSP2	11%	11.51%	13%
	SSP3	11%	12%	12%
Oil palm fruit	SSP2	71%	76%	76%
	SSP3	51%	56%	58%

*All textual analysis is based on SSP2 & RCP8.5, unless otherwise stated.

Rice

Results show that rice yields will increase roughly 30% from current levels across all climate and socio-economic scenarios. The area dedicated to rice production is strongly influenced by different SSPs, with a 1% decrease under SSP2, compared to a 6% increase under SSP3.

Coffee

Coffee is projected to experience a 35% increase in yield, which is the largest of all the crops examined. Responding to increases in suitability, the planting area for coffee is expected to rise by 11%. Much of this increased production is likely destined for international markets, with a projected 44% increase in coffee exports by 2050. The IMPACT model does not identify which areas of Indonesia will see the largest increases in suitability, however, with coffee production already encroaching on areas of primary forest it is critical to monitor where the projected expansion will take place so it can be effectively managed in a way that preserves Indonesia's globally important forests and peatlands (see *Agricultural Production Systems*).

Maize

Maize is projected to fare worse than all other crops examined over coming years, with a projected 5% decline in yields. Attempts to offset falling yields are likely to manifest as a 13% increase in planted area by 2050. Maize sees the largest percentage point disparity in yield under the differing climate change scenarios, with a 6pp drop in yield when comparing RCP4.5 with RCP8.5. This suggests that maize is highly sensitive to shifting atmospheric conditions and vulnerable to the resulting impacts of climate-induced hazards. While the trade deficit for maize is projected to increase under all future socio-economic and climatic scenarios, there is a 12pp reduction in the trade deficit under RCP8.5 when compared to RCP4.5. This suggests that Indonesia will outperform its principal trading partners under the more extreme climate change scenario.

Cacao

Cacao yields are projected to grow approximately 26% from current levels by 2050. However, despite the positive yield response, planted areas will be heavily influenced by social, economic, and political variables, with SSP2 results exhibiting an increase of 9% compared from current levels, but SSP3 showing a 2% decline. Net trade is projected to increase by 18% under both SSP scenarios, indicating the change in planting area is linked more to domestic factors than global trade preferences.

Oil palm fruit

Palm fruit exhibits a modest yield increase of between 3-6%, under future scenarios. However, this key cash crop is expected to have the largest increase in planted areas, with a 76% increase. A smaller yet still significant 58% increase in planted area is projected under SSP3. As processed palm oil is a major export commodity, it's unsurprising that increases in oil palm yield and planted areas are projected to result in a 90% increase in exports by 2050. Given the threat that expanded oil palm production poses to forest cover, peat land preservation, biodiversity, GHG emissions, and human health (related to fires), further analysis and policy action will be required to sustainably manage this growth (see *Policies and Institutions for CSA, Recommended Provincial CSA Package 2,* and *National Outlook*).

Impact of various socio-economic and climate change scenarios on livestock populations through 2050

Livestock numbers ('000 heads)

Commodity	Climate Scenario			
	SSP Scenario	NoCC	RCP4.5	RCP8.5
Beef cattle	SSP2	33%	33%	33%
	SSP3	28%	28%	27%
Lamb	SSP2	15%	15%	15%
	SSP3	9%	9%	9%

Pig	SSP2	10%	10%	10%
	SSP3	2%	2%	2%
Poultry	SSP2	12%	12%	12%
	SSP3	-1%	-1%	-1%

*All textual analysis is based on SSP2 & RCP8.5, unless otherwise stated.

Livestock

Animal numbers are largely expected to increase over the next 30 years, with only small variations in headcount occurring under varying climate change scenarios. This is indicative that livestock production in Indonesia is less impacted by climate change than by non-climate influences. However, the livestock sector is itself a significant source of GHG emissions and its expansion must therefore be considered within climate change planning processes.

Compared to current populations, the headcounts of beef cows, lamb, and pigs exhibit increases under all future scenarios. Poultry is an outlier to this trend, with headcounts expected to decrease slightly under an SSP3 scenario.

Beef cattle populations are projected to increase 33% by 2030–the largest increase of all livestock types. Indonesia is and is projected to remain a net importer of beef, with increased domestic production reducing its trade deficit by 44% by 2050.

Lamb populations are projected to increase between 9-15% by 2050. However, this growth in domestic supply will likely be outstripped by demand, with a 178% increase in Indonesia’s trade deficit. Under SSP3 the trade deficit is expected to increase 287% by 2050.

Despite being a predominantly Muslim country, Indonesia is also home to a sizable Christian population and a strong performing pork industry. Pig populations are expected to increase by 2% under SSP2 and by

10% under SSP3. As pork consumption is expected to increase at a lower rate than poultry or beef, this increased production would largely be exported, as shown by a projected 336% trade surplus by 2050.

Poultry production is strongly influenced by varying social, economic, and political scenarios, with a 12% increase in population observed under SSP2 compared to a 1% decline under SSP3. Although domestic production is projected to increase under SSP2, the trade deficit is also expected to narrow less under this scenario (144%), than under SSP3 (69%). This indicates a large discrepancy in domestic demand for poultry under the two SSP scenarios.

Impact of various socio-economic and climate change scenarios on net trade through 2050

('000 tonnes)

Commodity	Climate Scenario			
	SSP Scenario	NO CC	RCP4.5	RCP8.5
Rice	SSP2	992%	1316%	1503%
	SSP3	1692%	2095%	2390%
Cacao	SSP2	18%	19%	18%
	SSP3	18%	20%	18%

Maize	SSP2	-168%	-151%	-139%
	SSP3	-139%	-123%	-117%
Coffee	SSP2	34%	42%	44%
	SSP3	35%	43%	44%
Oil Palm Fruit	SSP2	84%	89%	90%
	SSP3	58%	62%	63%
Beef	SSP2	45%	44%	44%
	SSP3	43%	43%	43%
Lamb	SSP2	-165%	-172%	-178%

	SSP3	-291%	-291%	-287%
Pork	SSP2	333%	334%	336%
	SSP3	272%	273%	277%
Poultry	SSP2	-144%	-144%	-144%
	SSP3	-70%	-71%	-69%

Systemic challenges to the agricultural sector

Shortage of agricultural labour

The value proposition of Indonesia's agricultural sector is under attack on a number of fronts, causing labour to flee to other industries (see *Women and Youth in Agriculture*). Agricultural revenues are decreasing, profit margins are increasingly squeezed by middle-men, the national diet is shifting to incorporate more processed foods, investment is hard to come by, and climate and non-climate hazards are both more common and increasingly severe [116]. All of these factors are driving young Indonesians to seek higher value employment elsewhere, which is in turn driving rural-urban migration. Labour is a crucial agricultural input, the lack of which leads to decreasing yields and income.

Smallholders lack access to finance

Apart from the government-provided KUR credit system, most small-scale agricultural operators have no access to formal credit. Commercial finance institutions view the sector as too risky for investment, and a major issue in sourcing finance for CSA is the challenge of connecting large-scale investors with Indonesia's diffuse smallholder farming community. While there is appetite from the international finance community to underwrite climate-smart initiatives, operationalizing an investment package of the size that interests institutional investors requires extensive local groundwork. The initial recruitment and subsequent monitoring of thousands of smallholders spread across a large and varying geography poses a logistical hurdle that has proven difficult even for keen financiers to overcome. As a result, many smallholders resort to informal loans, while most go without any credit at all.

Value chain actors lack agricultural insurance mechanisms

While insurance is just one component of a holistic risk management strategy, insurance mechanisms that protect livelihoods, guarantee incomes, and protect against default are a critical part of the social safety net in rural communities [117]. But in Indonesia, insurance mechanisms that protect agricultural stakeholders from environmental and non-environmental hazards are exceedingly rare. While the Ministry of Agriculture began experimenting with production cost insurance for rice producers in 2015, high costs have inhibited adoption [118]. Since then, a similar insurance scheme has been rolled out for cattle producers but state-funded protection for the majority of agricultural actors is still absent. Commercial institutions, understanding well agriculture's risk profile, shy away from the sector. While agricultural insurance programmes that link smallholder coverage with CSA practices and technologies are being piloted elsewhere, they have yet to take hold in Indonesia. The Technical Centre for Agricultural and Rural Cooperation's yield-based index insurance initiative in Zambia, and the International Livestock Research Institute's (ILRI's) weather-index based insurance product for pastoralists in Ethiopia, may both serve as examples of models worth exploring. [119,120]. As smallholder farming is characterized by poverty and high exposure to environmental hazards, this lack of insurance leaves small producers highly exposed to risks and suppresses sectoral investment and growth.

Women's contribution to agricultural production is undervalued and restricted

While women form a core part of the agricultural labour force, providing both formal labour and unpaid domestic services, they are paid less, own fewer assets, and lack equal decision-making power [121]. While the Government of Indonesia is committed to women's empowerment and has worked to mainstream gender considerations into policy and planning processes, a key obstacle is the lack of gender disaggregated data in the agricultural sector/ Additionally, the resources and capacity to implement gender-based practices at the local level is often lacking [33]. Laws meant to level the playing field, including one related to the joint titling of property assets between husbands and wives, are often unenforced, while many Indonesians are unaware of their existence [33]. Men are often assumed to be the head of household, and unequal access to formal education and agricultural extension services perpetuate patriarchal decision-making structures and make it difficult for women to benefit from development interventions and formal support structures [121]. Customary socio-cultural practices, particularly around land and property rights, further disenfranchise women [33].

Extension services are often unavailable or underperforming

A lack of high quality, accessible agricultural extension services limits the productive capacity of farmers, the development of producer groups, the dissemination of environmentally sustainable practices and technologies, and the economic growth of the sector as a whole. Since 1999, the decentralization of government services in Indonesia has shifted administration of the national agricultural extension system to district and provincial governments [122]. Though services are nominally overseen by the MoA's National Center of Agricultural Extension and the training of extension officers is heavily dependent on a nationally-funded budget, services are designed and delivered locally [122]. However, as of 2018, just 18 of 34 Indonesian districts had established Extension Coordination Agencies [123]. Inadequate training and an aging workforce mean that extension officers are not always abreast of vanguard practices and digital technologies [122]. The overall number of extension workers has steadily decreased in recent years due to budgetary constraints, difficulties recruiting young workers to replace older ones as they retire, and low wages that render the work unattractive [123]. The combination of these factors has led to the government missing its own target of maintaining one extension worker per village across the country, severing a critical connection between small producers and improved practices. Going forward, improved technologies and connectivity are needed to compensate for insufficient human resources, and the private sector (input suppliers, agri-vet shops, and private extension agents) should be leveraged to support the implementation of product standards and improved training for producers [19].

Farmers lack reliable environmental and climatological advisory services

The absence of reliable climate advisory services means farmers often rely on intuition and custom to make production-related decisions–neither of which are well-equipped to navigate the risks posed by a rapidly changing climate. Though producers are sometimes able to access weather and climate forecasts through local offices of the Meteorology, Climatology, and Geophysical Agency (BMKG), this information is inconvenient to obtain and viewed by farmers as inaccurate. This issue is compounded by a lack of available extension services, which, while not a replacement, would ideally serve as a complementary force in bolstering smallholder resilience. In 2015, the BMKG began running Climate Field School based on the Farmer Field School model, in which farmers are trained to use simple forecasting tools and apply climatological and meteorological data to agricultural practices [124]. While the schools were largely successful in their aim of increasing the adaptive capacity of smallholders, closer coordination is needed between BMKG and MoA to improve and scale this model. Climate change should be mainstreamed into agricultural extension services, farmers must be able to easily access, understand, and action weather and climate forecasts, and advance notification of slow-onset climate risks and extreme weather events should be prioritized [125].

Indonesia's national fertilizer subsidy needs reforming

This desire of Indonesia's agricultural value chain actors for an expansion of fertilizer subsidies indicates a gap between local stakeholders and a growing body of researchers and development agencies. The latter believe the cost of fertilizer subsidies outweigh their benefits and that subsidies encourage unnecessary fertilizer application, resulting in environmental damage [19,126,127]. The Asian Development bank has recently called for the cost of fertilizer subsidies to be reinvested into national agricultural research, extension, and irrigation programmes, arguing that the output response from these investments would be larger. With US $2.1 billion spent on fertilizer subsidies in 2015 alone–compared to US $113 million on extension and US $128 million on research–the massive cost of the subsidy may indeed be spent in more fruitful ways, including direct payments to farmers and input suppliers (see *Recommended Provincial CSA Intervention Package 1*) [128].

Policies and Institutions for CSA

International policy frameworks

Indonesia's Nationally Determined Contribution

Submitted to the UNFCCC in November 2016, Indonesia's Nationally Determined Contribution (NDC) committed to a 29% unconditional reduction in business-as-usual (BAU) GHG emissions by 2030, and a 41% reduction conditional on international financial and technical support[6] [129]. As the fifth largest source of total GHG emissions and largest national source of forestry emissions, the success of Indonesia's NDC is critical to both global mitigation efforts and domestic development [90]. By 2030, Indonesia has unconditionally pledged to reduce forestry emissions by 70% against BAU, and by up to 91% against BAU with additional international support [129]. For agricultural emissions, it has pledged an 8% unconditional reduction, and a 3% reduction conditional on international support [129]. All the scenarios laid out in

[6] Though the text of the document indicates an emissions reduction of "up to 41% with international support," the quantitative targets and reduction strategies laid out in the NDC calculate the projected conditional reduction as 38% against BAU [123].

Indonesia's NDC[7] project a significant reduction in forestry emissions as a percentage of total, from 48% in 2010 to 25% (BAU), 11% (unconditionally), and 4% (conditionally) by 2030 [129].

This is due largely to rising emissions from the energy sector, which is projected to overtake forestry as Indonesia's primary source of emissions in coming years [129]. By 2030, the energy sector is expected to account for 67% and 71% of total emissions in unconditional and conditional scenarios, respectively, versus just 34% in 2010 [129]. While Indonesia may achieve its unconditional commitment to a 70% reduction in forestry emissions by 2030, it remains to be seen if Indonesia will meet its overall NDC target due to planned increases in GHG emissions from coal-powered energy [129,130]. Additionally, increasingly favourable conditions for growing oil palm, brought on by climate change, are projected to lead to an increase in cultivated areas, further threatening forestry-related emissions commitments (see *Economic Impacts of Climate Change).*

REDD+ Framework

In 2010, Indonesia signed a Letter of Intent with Norway in accordance with the UN Reducing Emissions from Deforestation and Forest Degradation (REDD+) Framework. In it, Norway pledged a direct financial contribution of US $1 billion to Indonesia in exchange for verified reductions in forestry emissions [125]. However, Indonesia's forestry emissions continued to rise, the setup of the measurement, reporting, and verification systems were delayed, and, in 2015, a change in government and subsequent administrative restructuring saw Indonesia's REDD+ coordination agency disbanded [131].

Norway ultimately agreed to disburse the first results-based payment in 2020, following a 60% annual reduction in the rate of deforestation in primary forests in 2016-17 (see *Current Financing Landscape and Financing Opportunities)*. A confluence of factors led to the reduction, including the introduction of new policies, such as a Presidential moratorium on the commercial development of peatlands, increased enforcement of existing restrictions against illegal forestry, a dry summer with relatively few forest fires, and reduced demand for palm oil production due to a dip in prices [132]. This US $56 million payment, in exchange for a reduction of 17 million tons CO2-eq, will be used for the restoration of peatlands and other critically degraded land [133]. Under a similar REDD+ scheme, in 2020 the Global Climate Fund also approved a US $104 million payment to Indonesia for emissions reductions in 2014-16 [133].

However, with emissions back on the rise in 2017-18, future payments are not guaranteed [88]. Further, as REDD+ funds are disbursed retrospectively they are mainly used to restore landscapes that have already been critically degraded [133]. Strengthened domestic policy frameworks and new international funding streams are needed to *pre-empt* the degradation of additional primary forests and peatlands. The financial incentives to preserve endangered landscapes must exceed those to cultivate them, and REDD+, though a promising policy tool, cannot achieve this alone. Critically, funds from these programmes must be

[7] The three scenarios are BAU, unconditional, in which Indonesia acts unilaterally, and conditional, in which Indonesia receives financial and technical support from the international community.

disbursed to local stakeholders in the villages and districts where future deforestation is most likely to occur. While new legal frameworks can provide the proverbial stick to punish agents of deforestation, they must also incentivise and reward the small producers who are being asked to sacrifice economic gains for environmental preservation [134]. Future results-based payment programmes should also incorporate targets for deforestation-free districts and the preservation of uncultivated primary forests and peatlands.

Sustainable Development Goals

To achieve Indonesia's Sustainable Development Goals (SDGs), CSA practices and technologies must be adopted at scale to ensure the resilience of agricultural communities, a steady domestic food supply, and local value capture from the export of key cash crops. Increased agricultural productivity, business development training for smallholder farmers, and improved extension services are key to achieving the national food security called for in SDG 2 ("Zero Hunger") [135]. The achievement of SDG 8 ("Decent Work and Economic Growth") relies on the agricultural sector's modernization, with improved management capacity, the ability of small farmers to scale their businesses, and the improvement of product quality and standards [135].

Calls to halt deforestation and increase community/social forestry feature prominently in several SDGs. Toward SDG 10 ("Reduced Inequalities"), social forestry is seen as a way of more equally distributing forest resources and helping agrarian communities reap greater value from their lands (see *Case Study: Social Forestry in West Kalimantan*) [135]. Improved forest management and reforestation are also critical to SDGs 13 and 15 ("Climate Action" and "Life on Land"). Both focus extensively on curbing deforestation by transferring the authority to manage forest resources to local communities, improving enforcement measures against illegal forestry, enabling 'Forestry 4.0' through improved technologies and information flows, and extending Presidential moratoriums on peatland development and the granting of new economic concessions in primary forests [135].

National institutions

Indonesia's climate change response is guided by the President and overseen by the Ministry of National Development Planning (Bappenas), which is responsible for operationalizing international policy frameworks through national development planning processes. Bappenas achieves this by coordinating with an assortment of national ministries and their subsidiary agencies, of which the Ministry of Agriculture (MoA) and the Ministry of Environment and Forestry (MoEF) work most directly to implement CSA. However, mandates often overlap across institutions and the success of national plans can depend on the ability of provincial or local institutions to effectively implement them. Bappenas oversees many of Indonesia's foundational climate change policies in addition to a plethora of non-climate or agricultural planning frameworks.

MoA also plays a significant role in CSA initiatives, particularly through its subsidiary organisations. These include the Agricultural Research and Development Agency, Food Security Agency, Agriculture and Human Resources Agency, Agricultural Technology and Spreading Center, Social Economic and Agricultural Policy Center, Data Center and Agricultural Information System, and Directorate Generals of Agricultural Infrastructure and Facilities, Food Plants, Plantations, and Animal Livestock and Animal Husbandry [136].

Additionally, MoA's Indonesian Center for Estate Crops Research and Development performs research related to many of Indonesia's high value export crops, including oil palm, rubber, coffee, and cocoa. The Center is mainly focused on increasing productivity and views adaptive measures–such as integrated farming systems–rather than mitigating measures as the best means of reducing GHG emissions, despite a significant portion of Indonesia's total emissions stemming from land conversion and reclamation for the production of estate crops like palm oil.

MoA's Agency for Agricultural Extension and Human Resource Development (AEHRD) aims to improve the quality and reach of extension services while boosting the sector's human capital–both of which are critical to the implementation of CSA practices. A federal drive to decentralize government services, begun in 1999, has posed a challenge for the delivery of extension services on a national scale [137]. To combat this, AEHRD works with provincial and local extension workers to ensure national priorities are reflected in local practices, and local concerns are incorporated into national planning [123]. AEHRD is also responsible for linking agricultural research and development with extension through farmer field schools, demonstration plots, and "training of trainers" programmes. Through the Integrated Farmer Empowerment Program (GPPT) and Farmers Regeneration Program (GRP), AEHRD aims to bring 2.5 million new millennial workers into the agricultural workforce, effectively doubling their sectoral representation. The Indonesian Center for Agricultural Technology Assessment and Development also sits within MoA and develops and disseminates new agricultural technologies through its 33 provincial Assessment Institutes for Agricultural Technology [138].

Institutions for CSA in Indonesia

	Institution	Key Activities
Mitigation Adaptation	**MoEF's Directorate General of Climate Change (DJPPI)** DJPPI is responsible for the formulation and implentation of climate change mitigation and adaptation policies at the national level	DJPPI sits within the MoEF and was formed in 2015 as the result of a Presidential decree merging the Ministry of Environment, Ministry of Forestry, and BPREDD+ Provides technical guidance and supervision for national and sub-national agencies related to climate change mitigation and adaptation Oversees REDD+ implementation at the national level Also overees the development of Norms, Standards, Procedures and Criteria (NSPK), and M&E for implementing mitigation and adaptation policies
Mitigation Adaptation Productivity	**MoA's Indonesian Agency for Agricultural Research & Development (IAARD)** IAARD oversees 11 R&D centers related to food crops, horticulture, estate crops, livestock, veterinary, soil and agro-climate, agro-socio economics, machinery development, post-harvest technology, biotechnology, and agricultural technology assessment Within these centers, IAARD manages 15 research institutions, 3 research stations and 31 assesment institutions across Indonesia.	First bullet point: Change to: IAARD develops technological innovations and policy recommendation to support the transition to a more sustainable industrial agricultural system IAARD aims to improve the quality of domestic agricultural R&D, while developing international networks to introduce improved practices and technologies to the sector
Adaptation Productivity	**MoA's Agency for Agricultural Extension and Human Resource Development (AEHRD)** AEHRD works with provincial and local extension workers to ensure national priorities are reflected in local practices, and local concerns are incorporated into national planning	AEHRD is responsible for linking agricultural research and development with extension through farmer field schools, demonstration plots, and "training of trainers" programmes AEHRD also administers the Integrated Farmer Empowerment (GPPT) and Farmers Regeneration Program (GRP), which aim to bring 2.5 millennial workers into the agricultural workforce It is also overseeing a push for the digitalization of extension services, such as providing extension services to farmers via phone calls and video conferences, CCTV for crop monitoring, the increased use of mobile phones and personal computers, and the ongoing development of a mobile application for internet-powered extension services
Mitigation Adaptation	**Bappenas' Indonesia Climate Trust Fund (ICCTF)** Established in 2009 to connect the activities laid out in the Regional/National Action Plans for Greenhouse Gas Emission Reduction (RAN/RAD-GRK) and the National Action Plan for Climate Change Adaptation (RAN-API) with international funding	As the only climate fund with a governmental mandate, the ICCTF is meant to help Indonesia finance its NDC commitments The ICCTF has so far funded 76 projects with another 13 ongoing 61% of projects are focused on land-based mitigation, with additional projects related to adaptation, resilience, and marine-based sustainability
Mitigation Productivity	**Indonesia's Social Forestry Programme (ISFP)** Established to achieve the 2015-2019 National Medium-Term Development Plan's (RPJMN) targets for Social Forestry and Forest and Land Rehabilitation (RHL), the ISFP is meant to transfer 12.7 million ha of government-regulated forest to the management of local communities	The ISFP aims to improve the quality of lifee of forest communities, protect Indonesia's stock of forests, and resolve tenurial land conflicts Training has also been provided on the sustainable production of forest commodities such as coconut shell charcoal, crabs, and honey Despite missing its 12.7 million ha target by 80% (as of April 2019), more than 2.6 million ha have been transferred to date

	Institution	Key Activities
Mitigation Adaptation Productivity	**Indonesia's Peatland Restoration Agency (IBRG)** In response to rampaging forest fires of 2015, the President established the BRG, which is independent of the official ministries and charged with restoring 2 million ha of peatland across seven severely impacted provinces by 2020	The BRG employs a "3R" process to peat restoration which spans all three pillars of CSA It involves rewetting the peat area through canal blocking and deep well construction, restoring its vegetation, and revitalizing local livelihoods by promoting animal husbandry, fishery production, honey bee farming, and zero-burning paddy rice production
Adaptation Productivity	**People's Business Credit (KUR) Programme** Launched in 2007, the KUR is a government subsidized credit programme that guarantees small loans and business credits for micro, small, and medium-sized enterprises (MSMEs) While loans don't come with CSA requirements, they come with a partial credit guarantee to work around issues of insufficient collateral and are designed to aid unbankable smallholders in developing their businesses	With interest rates lower than those offered by commercial banks and MFIs (and dropping), KUR loans have become increasingly popular among smallholder farmers, and successful in extending lines of credit to MSMEs that would otherwise go without
Mitigation Productivity	**Public Service Agency for Environment Fund Management (BPLDH)** In 2019, the Ministry of Finance and the Ministry of Environment and Forestry partnered to establish the BPLDH It is a new type of public service agency designed to combine public funding, private finance and international donations to finance projects targeting environmental protection and management	BPLDH is able to simultaneously manage different funding windows and is gearing up to receive funds from both the REDD+ and the Forestry Funds Mitigation and adaptation in forestry, agriculture, ecosystem services, and marine/aquaculture sectors will be prioritized It is hoped that the BPLDH's ability to disburse international funds directly to specific beneficiaries will prove attractive for donors with precise impact agendas
Mitigation Productivity	**Tropical Landscapes Funding Facility (TLFF)** Established in 2016 to leverage public funding for additional private financing of landscape-level investments related to Indonesia's SDGs and Paris Agreement commitments The TLFF is a partnership between the Coordinating Ministry for Economic Affairs, UN Environment, the International Centre for Research in Agroforestry, ADM Capital, and BNP Paribas	The TLFF is focused on agriculture, forest management, biodiversity, and ecosystem conservation and restoration In 2019, the TLFF issued Southeast Asia's first Corporate Sustainability Bond to stimulate $215M total investment for Royal Lestari Utama (RLU), a joint venture between Indonesia's PT Barito Pacific and France's Groupe Michelin Having been granted an 88,000 ha concession area in Sumatra and East Kalimantan, RLU plans to convert 34,000 ha to "climate smart, wildlife friendly, socially inclusive" rubber production, while preserving 54,000 ha for "community livelihoods and conservation

AEHRD is currently overseeing a push for the digitalization of extension services, with the construction of a self-described “agricultural war room” to map environmental conditions and land use throughout the country, and the development of *Kostratani*, or agricultural strategy command centres, in each of Indonesia’s districts. New practices include providing extension services to farmers via phone calls and video conferences, CCTV for crop monitoring, the increased use of mobile phones and personal computers, and the ongoing development of a mobile application for internet-powered extension services. Despite the agency’s new technologies, it is estimated that only half of Indonesia’s villages host a dedicated extension worker, which is a 50% shortfall against the Government of Indonesia’s own target of one per village. This is largely due to a lack of planning on how to replace extension agents as they retire; since decentralization this responsibility has fallen to district governments, who often lack the funds and capacity to recruit at the necessary scale (see *Challenges to the Agricultural Sector*).

Ministry-wide, MoA is implementing two major programmes of productive intensification: *Upsus Pajale*, for maize, rice, and soybean, and *Upsus Siwab*, for livestock. *Upsus Pajale* focuses on increasing the planted areas of key crops and increasing the productivity of farmers through input subsidies, the provision of new technologies for increased pre- and post-harvest mechanisation, and improved irrigation infrastructure, such as dams and canals [19]. *Upsus Siwab* aimed to increase beef production by 28% yearly through the end of 2019 via insemination drives, animal fattening, and community-based livestock breeding programmes [19].

In 2014, the Ministries of Environment and Forestry were merged into a single unit, the Ministry of Environment and Forestry (MoEF), and charged with developing and implementing environmental policies at the national level, and supervision thereof at the subnational level in partnership with provincial and local government [139]. Additionally, the MoEF’s remit included national forestry management and coordination of the REDD+ process [139]. The MoEF’s Directorate General of Climate Change (DJPPI) also assumed the responsibility of overseeing mitigation and adaptation policies, including the NDC process, which was previously overseen by the National Council on Climate Change.

Several non-ministerial government institutions are also influential in formulating and implementing CSA policies. In response to rampaging forest fires of 2015, the President established the Peatland Restoration Agency (BRG), which is independent of the official ministries and charged with restoring 2M ha of peatland across seven severely impacted provinces by 2020 [140]. BRG employs a “3R” process to peat restoration, which consists of rewetting the peat area through canal blocking and deep well construction, restoring its vegetation, and revitalizing local livelihoods by promoting animal husbandry, fishery production, honey bee farming, and zero-burning paddy rice production [141]. Despite mixed results–the number of fires grew by 60% between 2015 and 2018, followed by a particularly severe fire season in 2019–the BRG’S Head has argued that restored peatland burned at a lesser rate than that of unrestored peatland, and linked new fires to slash-and-burn clearing for palm oil production [142,143].

Bulog, the National Food Logistics Agency, is a state-owned enterprise responsible for the purchase, distribution, and price stabilization of rice and other staple crops deemed critical to national food security

[144]. Bulog is Indonesia's largest purchaser of rice, procuring around 2 million tonnes per year from domestic and international producers [145]. Historically, Bulog has struggled to stabilize prices in the midst of regional and global financial crises, global food shortages, collapsing commodity prices, domestic economic instability, and political initiatives to achieve food independence [144]. The Agency has recently begun administering the *Rastra* programme, which dates to the Asian Financial Crisis and involves direct deliveries of rice to poor households, and assists MoA in the implementation of *Upsus Siwab and Upsus Pajale* [144,146].

National policies

Indonesia's National Long-Term Development Plan 2005-2025 (RPJPN) is overseen by Bappenas and lays out the nation's overarching development strategy. Along with the UNFCCC, it informs climate-related policy in subsidiary national, regional, and sectoral planning. Noting the threat that conventional agriculture poses to rural ecosystems, primary forests, and water resources, the RPJPN identifies three long-term challenges–food, water, and energy security–that CSA can help to remedy [147]. The RPJPN positions agriculture as an engine of rural development, calls for the improvement of rural infrastructure, targets increased efficiency, modernization, and value-addition in the agricultural sector, and generally views increased agricultural productivity as an important means of advancing Indonesia's socio-economic development and global competitiveness [147].

Downstream of the RPJPN lies Indonesia's five-year Medium-Term Development Plan (RPJMN), currently in its 2020-2024 phase and also administered by Bappenas. CSA measures feature prominently in the recently completed 2015-2019 phase, in which GHG emission reduction targets were laid out for five priority sectors in line with Indonesia's National Action Plan for Climate Change Adaptation (RAN-API), including forestry/peatlands and agriculture [148]. The RPJMN also established Indonesia's Social Forestry Program to transfer 12.7 million ha of government-regulated forest to the management of local communities [148]. Though this target is still far from being reached, where implemented, social forestry can lead to improvements in food security, land tenure, and income generation (see *Case Study: Social Forestry in West Kalimantan*) [149]. However, social forestry also depends on larger institutional changes in governance structures and habits, reduces state control over resources and thus is frequently implemented half-heartedly, and often lacks accompanying support and capacity building initiatives for communities [150]. SDG targets feature prominently in the RPJMN, with 94 of 241 indicators in direct alignment [135].

Case Study: Social Forestry in West Kalimantan

Mitigation benefits

- Maintaining forest cover benefits carbon sequestration

Adaptation benefits

- Social forestry improves local food security

Productivity benefits

- Increased access to land allows farmers to utilize forest resources to generate income
- Ecosystem services provided by forests are secured

Challenges to adoption

- Farmers lack finance to invest
- Procedures to obtain permits are not easy and farmers are often not well informed
- Village forests are supposed to be managed by a village enterprise. Not all villages have established an enterprise or are capable of managing an enterprise
- Outward migration can cause labour shortages, although, recently, COVID-19 has resulted in the return of many to the community

Background

Agrarian reform and social forestry (SF) are flagship programmes of the current government in Indonesia, which has earmarked 12.7 million ha of forest, or approximately 10% of the total forest area claimed by the state, for transfer to the control of local communities under SF schemes. Ostensibly, SF is intended to overcome poverty, unemployment, and injustice (Considerance, 2016). SF schemes fill into five different categories, of which only customary forest provides recognition for full community ownership. The four others involve management rights given to village enterprises (village forests or hutan desa), communities/farmer groups (community forest), and individuals or cooperatives (community plantations). Through 2019, approximately 4 million ha of forests have been converted to licensed social forests, with village forests the most common type.

In 2017, the village of Mensiau in Kapuas Hulu, West Kalimantan was awarded a village forest of 10,938 ha. The village itself is a little over 75,000 ha and borders Betung Kerihun National Park, which is mostly state forest. In addition to the village forest, Mensiau seeks to claim another 15,000 ha of customary forest and 10,000 ha of community forest. In fact, they are hoping to claim the legal rights to forest areas covering more than the 75,000 ha of territory the village currently comprises. In theory, the SF program could provide a legal avenue for these claims. However, SF licenses carry legal responsibility to protect and manage the forest, and are constrained by state-imposed restrictions on sites, usage types, and access; these limitations often complicate diverse local governance practices and customary informal rights (Erbaugh, 2019; De Royer et al., 2018; Wong et al, 2020; Bong et al. 2019).

To obtain a SF permit, communities must develop a technical proposal documenting proof of an established community institution or cooperative to manage the forest, the boundaries of the area to be managed, and an approved management plan (Moeliono et al., 2017; Fisher et al., 2018). Furthermore, although villages have gained a certain degree of autonomy through the Government of Indonesia's Law 6/2014 on Villages, they are still bound by the bureaucratic processes of their district government. Forestry, however, falls under the authority of provincial governments, while SF permits are issued by the national government. This distribution of oversight responsibility across various levels of government complicates communities' efforts to manage social forests, and often results in a lack of support from district governments. While village forests are often allocated a significant budget for development, all plans need to be approved by the district and development funds are often used for infrastructure rather than social forestry.

Despite these challenges, SF remains the most feasible means for local communities to gain legal rights to forest land and resources. With management periods lasting up to 35 years and extendable, rights are often secured for multiple generations.

Practice description

FORCLIME, a German government and GIZ-funded programme to reduce GHG emissions in the forestry sector and improve rural livelihoods, is supporting Mensiau's bid to obtain village forest management rights by helping the village form the administrative structures and technical plan required for a successful village forestry bid.

If successful, the hutan desa (HD) will be managed by a special village body, in this case the LPHD, which is the village forest management body under the village government. In other social forests, villages have established village enterprises to manage hutan desa areas, as recommended by the government. However, non-enterprise management bodies have greater flexibility to manage the forest, and may also help to minimize elite capture.

The LPHD is administered by a chair, secretary, and treasurer, who will implement a technical forest management proposal that includes economic plans for the forest's environmental services, such as nature-based tourism and the production of bottled water. As is usual in Indonesia's HDs, in Mensiau, income is generated by crop production (ginger), forest honey cultivation, and freshwater fish from a local pond. Experimentation has also begun with the local cultivation of lemongrass, and plans are in place to reforest the hutan desa area with fruit and timber trees. Additionally, 10,000 forest trees will be planted outside the HD's formal boundaries. For the most part, the village forest will be managed in the traditional manner of swidden cultivation, creating a mosaic landscape of swidden fallows, young and old fallows, rubber and tree gardens, and protected areas of old growth forest.

However, the establishment of new administrative structures places a greater strain on traditional social structures, which are struggling for survival in the face of state bureaucratization. Additionally, the LPHD's implementing capacity is low, and not all rules and regulations related to the LPHD and the hutan desa in general have been put into practice. For example, locals have so far been unable to prevent people from outside the village to come and hunt in the HD area.

Enablers

A key enabler for the expansion of SF is capacity building of the village institutions and organizations that must apply for licenses/permits and, if successful, sustainably manage the land. In many cases, capacity building is performed by non-governmental organizations. In Mensiau, FORCLIME has implemented institutional capacity building interventions involving the development of technical forest management proposals and conflict resolution training. The organization has also provided direct support for field activities in the hutan desa, such as the production of organic pesticides, the development of non-timber forest products, and other sustainable agroforestry practices (FORCLIME, 2020).

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Indonesia's National Action Plan for Greenhouse Gas Emission Reduction (RAN-GRK), enacted in 2011, is also managed by Bappenas and intended both as a national framework for achieving the GoI's 2020 mitigation targets[8] and as a precursor for Indonesia's forthcoming Nationally Appropriate Mitigation Activities (NAMAs)[9] [151]. The RAN-GRK was intended by Bappenas to guide the development and implementation of Regional Action Plans for Greenhouse Gas Emission Reduction (RAD-GRK), which were subsequently developed by provincial assemblies in order to operationalise the RAN-GRK at local level [153].

Forestry and the "land-based" sector feature heavily in the RAN-GRK, which is closely aligned with Indonesia's REDD+ framework. Both call for improved fire control, water management, forestry and land rehabilitation, community forestry management, enforcement measures against illegal logging, and the general empowerment of forest-based communities [153]. While the RAN-GRK articulates general practices to reduce agricultural emissions, like the proliferation of low-emission rice varieties, improved water efficiency and irrigation, and greater use of organic fertilizers, it largely leaves the details to be worked out in the RAD-GRKs and NAMAs [153]. None have specifically been formulated with reference to the agriculture or forestry sectors.

Complementing the RAN-GRK, Bappenas' National Action Plan for Climate Change Adaptation (RAN-API), published in 2013, is not legally binding but informs cross-sectoral adaptation policies in national and local development planning . In its risk assessment, the RAN-API found Indonesia's seven regions to be at moderate, high, or very high risk for 91% of the climate change hazards assessed, with Java, Bali, and the Sumatra islands most vulnerable [153]. Forecasting climate change's negative impact on future food production, the plan calls for the development of climate-adaptive farming systems and fisheries as a means of safeguarding national food security.

To combat these risks, the RAN-API identified enablers and actions to be implemented at the local and national levels. Nationally, this is to be achieved through crop and livestock diversification, infrastructure upgrades, the introduction of new, climate adaptive technologies, and the dissemination of climate-smart information and communications technology (ICT) systems [153]. Required enablers at the national level include capacity building for local stakeholders, the development of accurate climate information systems, increased research and development of adaptive technologies, and improvements in adaptation-related monitoring and evaluation [153]. At the regional level, ground-level CSA adoption will require improved extension services, the establishment of farmer cooperatives, wider availability of high-quality seeds, the construction of infrastructure to protect from tidal and flood abrasion, enhanced water efficiency and water impounding abilities, and reforestation [153]. Locally, CSA components play a key role in developing ecosystem resilience. The sustainable management of productive lands and improved

[8] A 26% reduction in GHG emissions due to the unilateral domestic implementation of NAMAs, and an additional 15% contingent on internationally supported NAMAs [151].

[9] NAMAs for Palm Oil Mill Effluent (POME LAMA), Smart Paddy (SMART), Community Forest Partnership for Wood Biomass Based Energy (CFFBE NAMA), Agroforestry for Rehabilitation of Degraded Land, and Sustainable Peatland Management in Indonesia are still classified as "under development" or undergoing feasibility studies [152].

governance/rehabilitation of essential ecosystems–such as coral reefs and primary forests–and endangered animal species are all highlighted as priority interventions [153].

Policies for CSA in Indonesia

Timeframe	Policy	CSA Pillars
2015 - 2030	**Sustainable Development Goals** **SDG 2 Zero Hunger:** Calls for the achievement of national food security through increased agricultural productivity, business development training for smallholder farmers, and improved extension services **SDG 8 Decent Work and Economic Growth:** Calls for agricultural modernization through improved management capacity, assistance for small farmers to scale their businesses, and the improvement of production quality and standards **SDG 10 Reduced Inequalities:** Social forestry is seen as a way of equally distributing forest resources and helping forest-based communities reap greater value from their land **SDG 13 Climate Action + SDG 15 Life on Land:** Reducing deforestation through community forestry management, improved enforcement against illegal forestry, enabling 'Forestry 4.0' through improved technologies and information flows, and extending Presidential moratoriums on peatland development and new economic concessions in primary forests	Mitigation Adaptation Productivity
2016 - 2030	**Nationally Determined Contribution** Commits Indonesia to a 29% unconditional reduction in business-as-usual (BAU) GHG emissions by 2030; up to a 41% reduction in BAU GHG by 2030 conditional on international financial and technical support; a 70% unconditional reduction in forestry emissions by 2030; up to a 91% reduction in forestry emissions by 2030 conditional on international support; an 8% unconditional reduction in agricultural emissions by 2030, and; a 3% reduction in agricultural emissions by 2030 conditional on international support	Mitigation
2010 - 2030	**UN REDD+ Framework / Letter of Intent with Norway** In accordance with the UN REDD+ Framework, in 2010, Norway pledged a direct financial contribution of US $1 billion to Indonesia in exchange for verified reductions in forestry emissions US $100 million was paid up front and another US $900 million was to be delivered over the next 3-4 years as results-based payments In 2018, Norway agreed to the first results-based payment and is now in the process of compensation Indonesia US $56 million for 11.2 million tons of CO_2 emission reductions from 2017	Mitigation Adaptation Productivity
2015-2019 + 2020-2024	**National Medium-Term Development Plan (RPJMN)** CSA measures feature prominently in the recently completed 2015-2019 phase, in which GHG emission reduction targets were laid out for five priority sectors in line with Indonesia's National Action Plan for Climate Change Adaptation (RAN-API), including forestry/peatlands and agriculture The RPJMN also established Indonesia's Social Forestry Program to transfer 12.7 million ha of government-regulated forest to the management of local communities SDGs feature prominently in the RPJMN, with 94 of 241 indicators in direct alignment	Mitigation Adaptation Productivity
2012 - 2030	**National Action Plan for Climate Change Adaptation (RAN-API)** The RAN-API is not legally binding but informs cross-sectoral adaptation policies in national and local development planning In its risk assessment, the RAN-API found all seven of Indonesia's regions to be at moderate, high, or very high risk for 91% of the climate change hazards assessed, with Java, Bali, and the Sumatra islands the most vulnerable The RAN-API calls for the development of climate-adaptive farming systems and fisheries as a means of safeguarding national food security, for the sustainable management of productive lands, and improved governance of essential ecosystems	Adaptation Productivity

Timeframe	Policy	CSA Pillars
2011 - 2025	**National Action Plan for Greenhouse Gas Emission Reduction (RAN-GRK)** Forestry and the "land-based" sector feature heavily in the RAN-GRK, which is closely aligned with Indonesia's REDD+ framework Both call for improved fire control, water management, forestry and land rehabilitation, community forestry management, strengthend enforcement against illegal logging, and the general empowerment of forest-based communities Meant to guide the development and implementation of Regional Action Plans for Greenhouse Gas Emission Reduction (RAD-GRK), which were subsequently developed by provincial assemblies in order to operationalise the RAN-GRK at local level	Mitigation
2016	**Government Regulation No. 57/2016** Permanently halted the issuance of new forestry licenses on peatlands Scaled back in 2019 to exclude areas outside of the "peat dome," or the thickest, most central part of the peat layer However, it may not be possible to protect 30% of the peatland ecosystem while allowing production ino the surrounding 70%, meaning a holistic "landscapes" approach may be required to prevent further subsidence, emissions, and fires	Mitigation
2011	**Presidential Instruction No. 10 Year 2011** Established a national moratorium on the issuance of new economic concessions for forestry production within certain land use areas Though the moratorium's enforcement has been uneven and deforestation initially continued to increase, those numbers then declined steadily, if slightly, through 2018 Was extended several times and made permanent in 2019	Mitigation Adaptation Productivity
2017	**Finance Ministerial Decree Number 94/PMK.02/2017** Issued by Indonesia's Financial Services Authority, this decree requires all ministries to track green investment It is hoped that the green budget tagging system will provide greater visibility of how funds are deployed nationally and coax more international financiers to invest in national projects related to sustainability	Productivity

In addition to structural legislative frameworks, various Presidential acts have the potential to significantly enhance Indonesia's progress on CSA. Presidential Instruction No. 10 Year 2011 established a national moratorium on the issuance of new economic concessions for forestry production within certain land use areas. The moratorium was extended several times and made permanent in 2019. While several at-risk land types are exempted from the moratorium, the decree has the potential to protect an area of forest roughly twice the size of Japan [139]. Though the moratorium's enforcement has been uneven and deforestation continued to increase nationally through 2015, in an encouraging turn of events those numbers then declined steadily, if slightly, through 2018 [154]. These are important though fragile gains, as evidenced by annual increases the same year in regional deforestation rates across East Kalimantan, Maluku, and West Papua provinces [139].

Similarly, Government Regulation No. 57/2016, permanently halted the issuance of new forestry licenses on peatlands, but was scaled back in 2019 to exclude areas outside of the "peat dome," or the thickest, most central part of the peat layer [139]. However, it may not be possible to protect 30% of the peatland ecosystem while allowing production in the surrounding 70%, meaning a "landscapes" approach may be required to prevent subsidence, emissions, and fires [155]. Improved monitoring of groundwater levels, ending the continuous revision of the borders of protected areas, and more zealous enforcement of the moratorium and its related punitive measures would likely increase the policy's efficacy [156].

Financing CSA

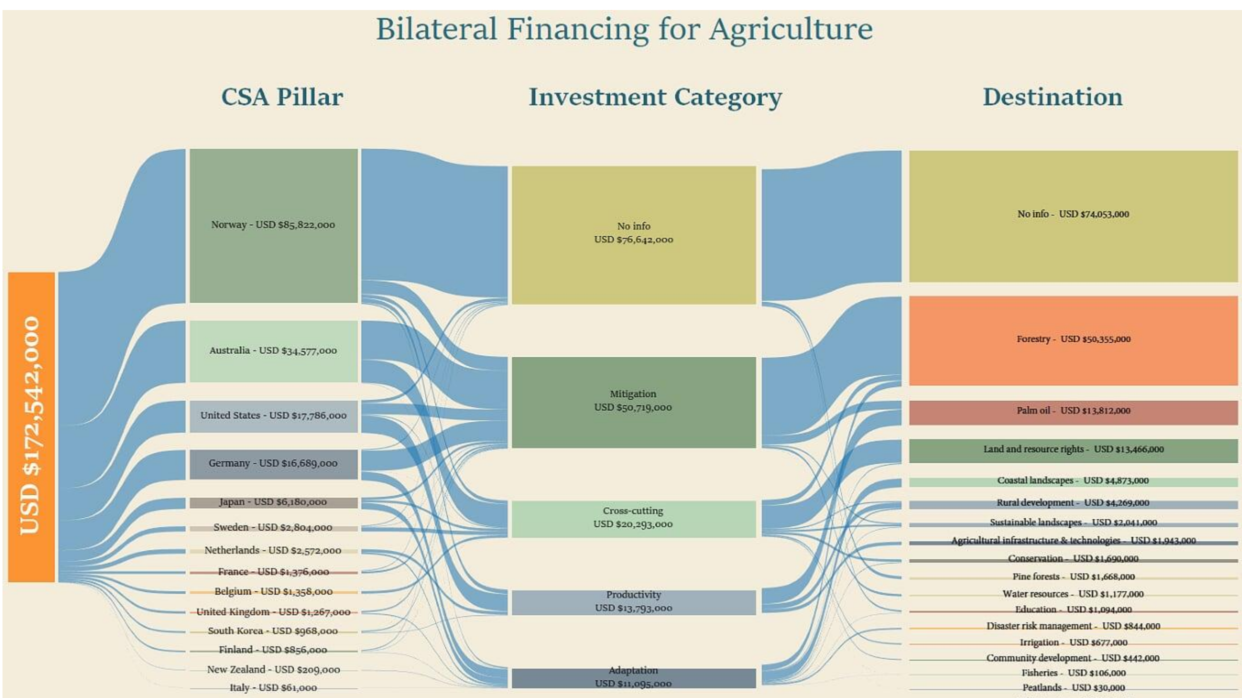
Current financing landscape

Funding for climate-smart agricultural initiatives in Indonesia comes from the government, international organizations, the private sector, and farming communities. Through national, provincial, and local budgets, the Government of Indonesia invests in programmes to implement policy initiatives. These investments are often complemented by funding from multinational development organisations, such as the World Bank, the International Fund for Agricultural Development, or the Food and Agriculture Organisation of the United Nations, or bilateral national donors, such as the Japan International Cooperation Agency, the Australian Centre for International Agricultural Research, or the United States Agency for International Development. International donors tend to invest in realizing international policy frameworks, such as the SDGs or an NDC, locally. Private sector finance comes from corporations, commercial finance institutions, institutional investors, private equity firms, and venture capitalists. Blended financial instruments, combining public or philanthropic funds with private investments, can be employed to stimulate private finance in the sector by reducing investment risk.

In 2016, approximately 96% of the US $30 billion invested in the Indonesian agricultural sector was provided by farmers themselves in the form of land development, small-scale infrastructural upgrades, and supporting facilities [19]. Public funding from state, provincial, and local budgets comprised approximately 4%, and private sector investment was smaller, likely due to low growth potential and a shaky investment environment [19]. While Indonesia is the sixth largest recipient of public climate financing globally, a large portion of funding is dedicated to green energy rather than climate-smart agriculture, despite LULUCF and agricultural emissions outpacing energy emissions threefold [157].

During 2015 and 2016, Indonesia received an annual average of US $952 million in bilateral climate-related development finance from OECD donors, the three largest being Norway, Australia, and the United States [157]. Of the 2016 total, just 18% of funds, or approximately US $182 million, went toward projects related to agriculture [128]. Multilateral donors are also a major source of CSA funding for Indonesia. According to the World Bank's (WB) 2016-2020 Country Partnership Framework for Indonesia, sustainable landscapes are a key engagement area [158]. With an average of US $1.7 billion in annual lending, the WB funds many projects incorporating CSA, including the Strategic Irrigation Modernization and Urgent Rehabilitation Project (SIMURP). Worth US $578 million and running from 2018-2024, SIMURP aims to rehabilitate and modernize 100k ha of gravity upland and tidal gravity lowland irrigation systems [158]. The International Fund for Agricultural Development (IFAD) is currently funding five ongoing projects worth a total of US $1.8 billion, targeting a wide-range of CSA components, including integrated farming systems, youth entrepreneurship, rural empowerment, integrated participatory development, irrigation management, and village economic transformation [159]. The Asian Development Bank (ADB) is financing 278 agriculture, natural resources, and rural development-related projects worth US $4.93 billion, or 13% of their total investment in Indonesia through 2018 [160]. ADB currently has 13 CSA-related projects active or approved in Indonesia, though exact investment levels are difficult to estimate as many projects are regional [161].

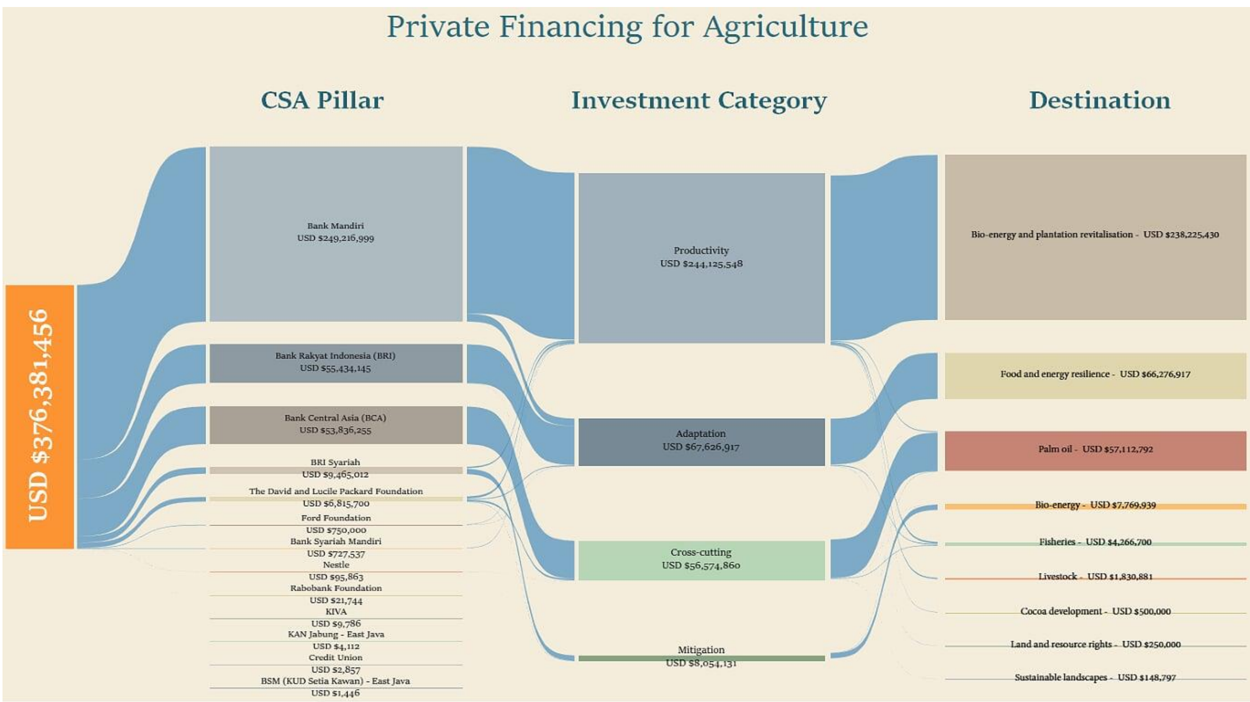
Bilateral finance for agriculture, 2016



[157]

Private sector financing for Indonesian agriculture totaled US $376 million in 2016[10] [162]. Approximately US $368 million was issued by Indonesian commercial banks as debt to SMEs for the agriculture and fishery sector, while the remaining US $8 million took the form of grants from private foundations. Bank Mandiri is the largest lender, investing US $249 million into a single plant-based energy and estate crop revitalization project, which is detailed later in this section. The David and Lucile Packard Foundation awarded approximately US $6.8 million in grants to finance the improved management of Indonesian fisheries. In general, investors prioritized bio-energy, plantation revitalization, sustainable oil cultivation, and food and energy resilience.

Private finance for agriculture, 2016



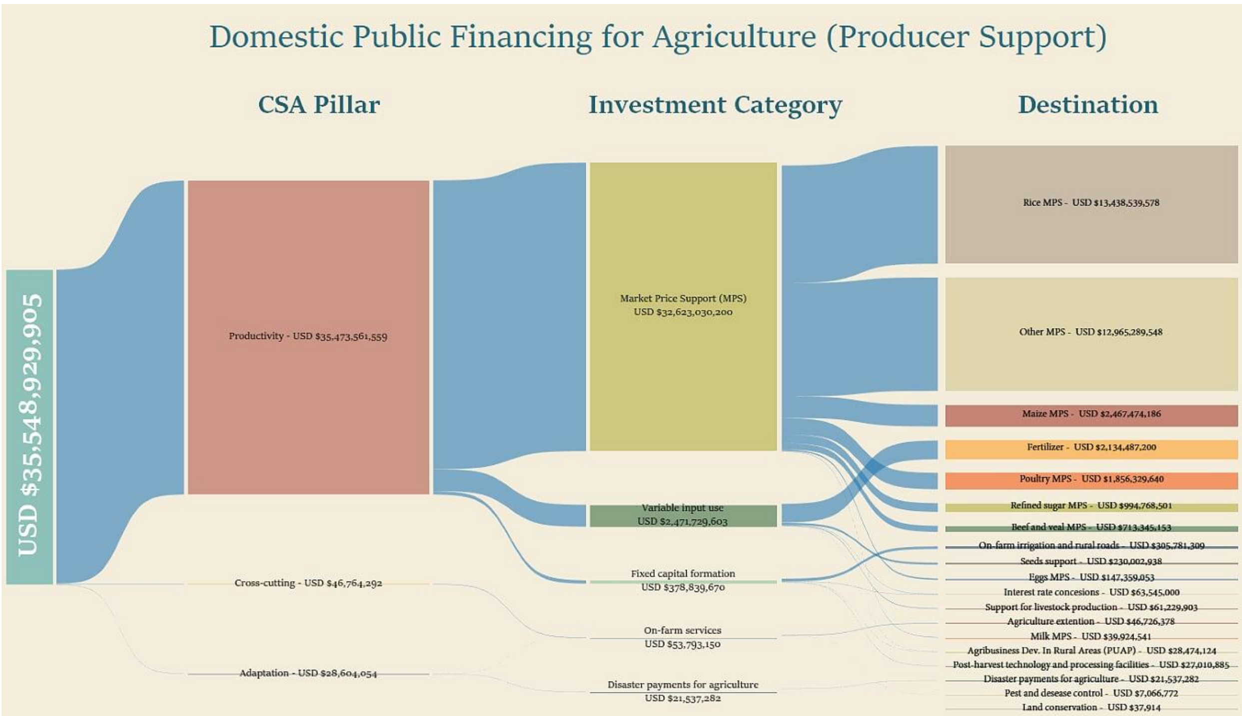
[162]

In 2015, the Government of Indonesia invested US $37.5 billion into the agricultural sector through a combination of producer support mechanisms (US $35.5 billion) and funding for general services (US $1.9 billion) [128]. Producer support mainly took the form of market price support mechanisms (MPS) and the input subsidies. Nearly half of all MPS went to rice producers, followed by a combination of unspecified commodities, and maize. Fertilizer subsidies accounted for US $2.1 billion of total. Irrigation is by far the best-funded general service, receiving US $1.0 billion in direct funding and a significant amount of specially allocated funding (US $596 million) [19]. Following irrigation are agricultural research and development

[10] This number may under represent the total amount of private finance invested in Indonesian agriculture, as some flows–particularly foreign direct investment–are difficult to track. A 2019 report by the Asian Development Bank places the value of foreign investment at US $1.35 billion in 2016 [19].

(US $128 million) and extension services (both the services themselves and the training of extension officers) (US $70 million).

Domestic public finance for agriculture (producer support), 2015



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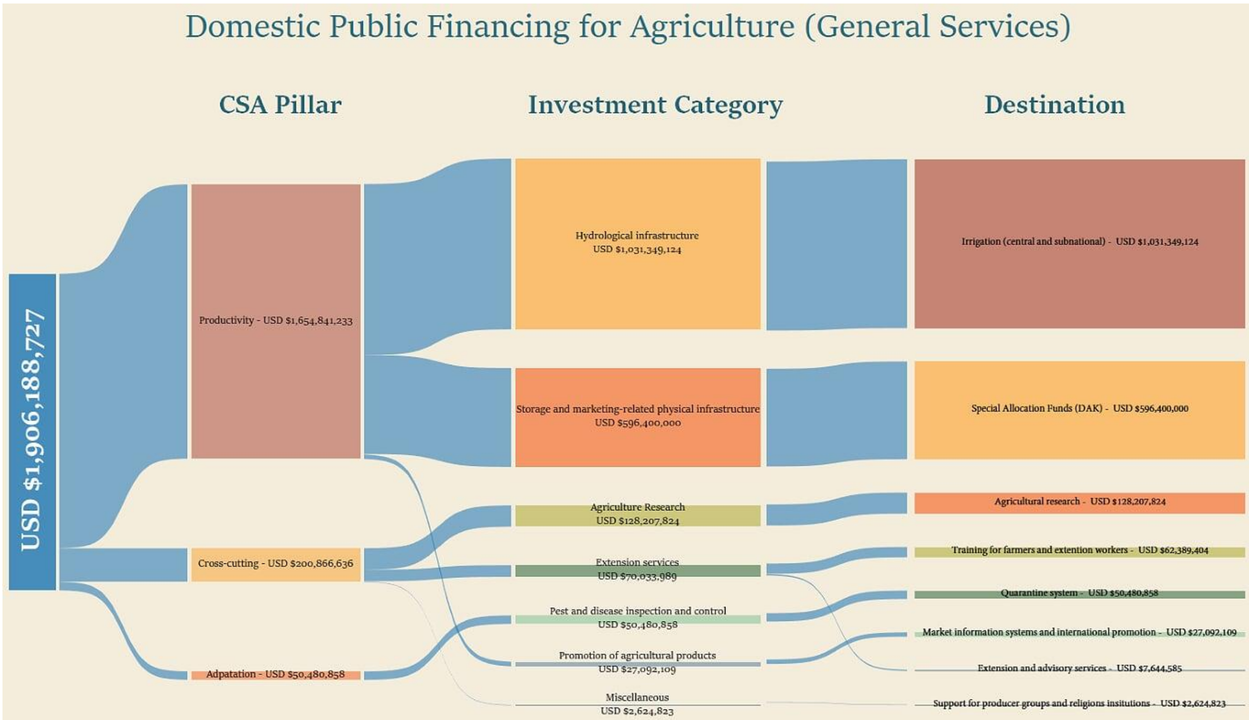
Domestic public finance for agriculture (general services), 2015



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The UNFCCC's mitigation and adaptation financing mechanism, the Green Climate Fund (GCF), is also active in Indonesia, with the Fiscal Policy Agency (BKF) of the Ministry of Finance acting as its National Designated Authority [163]. Despite CSA, sustainable forest management, and food security featuring prominently in the GCF's Initial List of National Mitigation and Adaptation Priority Areas, the Fund's two projects in Indonesia to date have focused on clean energy projects and received US $200 million in GCF funding [163,164].

A financial obstacle for many of Indonesia's smallholder farmers is that they aren't bankable and thus can't access formal credit mechanisms. Though microfinance institutions (MFIs) and small-scale rural banks (BPRs) are widespread and offer small and micro-sized loans, these schemes still carry high interest rates–upwards of 8%, with Indonesia enjoying the highest banking margins in Asia–and require economic collateral to access [165]. This has led to the proliferation of informal credit schemes, in which family members, friends, local moneylenders, or value chain actors like input suppliers and off takers provide loans in exchange for a cut of future profits [166]. In 2010, it was estimated that 37% of smallholder farmers had accessed informal credit, using social rather than economic collateral to secure loans [166]. As more Indonesians own smartphones than have a bank account, digital payments through smartphone apps, like GoPay, have become a common way of executing financial transactions.

To remedy this, various public finance schemes have been implemented by the GoI with differing levels of success. Recently, Indonesia's Central Bank launched a series of credit and loan schemes for small farmers[11] in which credit is disbursed through local credit unions in alignment with national policy objectives [167]. Similarly, a system of Farmer Cards, or Kartu Tani, were distributed to farmers pre-loaded with credit that could be used to purchase input supplies. However, the scheme became entangled in local politics and high requirements for access has hindered adoption. Additionally, the MoA has recently launched an insurance scheme for paddy rice and cattle, in which the Ministry co-funds 75% of the cost of the scheme.

The People's Business Credit (KUR) programme, launched in 2007, is a government subsidized credit programme that guarantees small loans and business credits for micro, small, and medium-sized enterprises (MSMEs). While loans don't come with CSA requirements, they come with a partial credit guarantee to work around issues of insufficient collateral and are designed to aid unbankable smallholders in developing their businesses [168,169]. With interest rates lower than those offered by commercial banks and MFIs–and dropping from 22% in 2015 to 6% in 2020–KUR loans have become increasingly popular among smallholder farmers, and successful in extending lines of credit to MSMEs that would otherwise go without [170,171]. Similar government programmes specifically targeting the agricultural sector, such as the Food Security and Energy Credit (KKPE), Credit for Energy Development and Plantation Revitalization (KPEN-RP), and the Business Credit for Cow Breeding (KUPS) have also grown in popularity [167].

Public service agencies (BLUs) also play a significant role in managing climate finance in Indonesia. BLUs have proliferated since the early 2000s, when they were first adopted as a vehicle for stimulating agile management and financial flexibility in the delivery of public services [137]. Whereas government institutions must remit collected revenues to the treasury and then withdraw them again for use, BLUs manage their funds independently, allowing them greater speed and flexibility in funding public services [137]. They are also meant to have greater social accountability than state-owned enterprises, which are initially funded with state funds but then operate as limited liability, for-profit companies [172]. BLUs are essentially government enterprises that employ state revenues on a semi-commercial, fiduciary basis–through direct spending or investments–to deliver non-profit services [172]. A wide variety of BLUs operate across Indonesia's agricultural, forestry, and marine sectors, including the Revolving Fund for Cooperatives and Micro SMEs, the Forestry Fund, and the Public Agency for Palm Oil Fund Management, whose beneficiaries are mainly in the private sector, and the Revolving Fund for Maritime and Fisheries SMEs, and the Ultra Micro Financing Fund, whose beneficiaries are mainly community service organisations and individuals [172].

In 2009, the Indonesia Climate Trust Fund (ICCTF) was established within BAPPENAS to connect the activities laid out in the RAN/RAD-GRK and the RAN-API with international funding from bilateral and multilateral donors [173]. As the only climate fund with a governmental mandate, the ICCTF is meant to

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[11] Such credits include the Food Security and Energy Credit, Credit for Energy Development and Plantation Revitalization, Business Credit of Cow Breeding, and the People's Business Credit [162].

play an instrumental role in Indonesia's achievement of its 29% unconditional and 41% conditional emissions reductions by 2030. Governmental institutions (local and national), as well as executing agencies may apply for funds related to land-based mitigation efforts, green energy development, adaptation and resilience initiatives, or marine-based sustainability projects [174]. However, the Fund began with a small endowment of just $11M, was initially slow to approve disbursals, was not successful in achieving Adaptation Fund accreditation, and is still working toward GCF certification [175]. The ICCTF has so far funded 76 projects, with another 13 ongoing, and 61% of projects focused on land-based mitigation [176].

While Indonesia is also a major destination for private climate finance, more than half of these flows target renewable energy, with agriculture, forestry, and other land use (AFOLU) comprising approximately 16% of total receipts from 2015-2018, or US $2.1 billion total [177]. Nearly 60% of private finance comes from commercial finance institutions, followed by institutional investors (16%), project developers (13%), and corporate actors (9%) [177]. Commercial debt financing is the most common vehicle for funding, and comprises approximately 75% of all private climate finance [177].

In 2016, the Tropical Landscapes Funding Facility (TLFF) was established as a partnership between the Coordinating Ministry for Economic Affairs, UN Environment, the International Centre for Research in Agroforestry, ADM Capital, and BNP Paribas [178]. Set up to leverage public funding for additional private financing of landscape-level investments related to Indonesia's SDGs and Paris Agreement commitments, the TLFF is focused on agriculture, forest management, biodiversity, and ecosystem conservation and restoration. In 2019, the TLFF issued Southeast Asia's first Corporate Sustainability Bond to stimulate $215M total investment for Royal Lestari Utama (RLU), a joint venture between Indonesia's PT Barito Pacific and France's Groupe Michelin. Having been granted an 88,000 ha concession area in Sumatra and East Kalimantan, RLU plans to convert 34,000 ha to "climate smart, wildlife friendly, socially inclusive" rubber production, while preserving 54,000 ha for "community livelihoods and conservation" [179]. In total, the plan is expected to generate 16,000 local jobs [179].

Similarly, UN Environment and Dutch Rabobank have partnered to establish the AGRI3 Fund in hopes of raising US $1 billion in private financing for sustainable, deforestation-free agricultural and land use [180]. Aiming to influence sustainable land use practices at scale, AGRI3 operates globally but targets smallholder inclusivity and emissions mitigation through forest conservation and responsible agrochemical use in the Indonesian coffee, cacao, and aquaculture sectors [180]. In Indonesia, the fund plans to target cacao and coffee value chains, as well as the aquaculture sector and, more broadly, landscapes [180].

Financing opportunities

In recent years, Indonesia has taken steps to bring in more private finance for climate change initiatives. In a bid to stimulate additional investment, Indonesia's Financial Services Authority issued Finance Ministerial Decree Number 94/PMK.02/2017, requiring all ministries to track green investment. It is hoped that the green budget tagging system will provide greater visibility of how funds are deployed nationally, and coax more cautious donors to invest in national projects related to sustainability [177]**.**

In 2019, the Ministry of Finance and the Ministry of Environment and Forestry partnered to establish the Public Service Agency for Environment Fund Management (BPLDH). BPLDH is a new type of public service agency, designed to combine public funding, private finance and international donations to finance projects targeting environmental protection and management. Within that broad remit, climate change mitigation and adaptation in the forestry, ecosystem services, agriculture, and marine/aquaculture–as well as energy, transportation, and carbon trading–sectors will be prioritized [172]. A key innovation is that the BPLDH is able to receive international funds and disburse them to specific beneficiaries according to the donor’s requirements; it is hoped that this granularity in fund distribution will prove attractive for donors with precise impact agendas. Unlike other BLUs, the BPLDH is able to simultaneously manage different funding windows, and is gearing up to receive funds from both the REDD+ and the Forestry Funds [172].

To connect international investors directly with producers (see *Challenges to the Agricultural Sector*), various fintech startups have used peer-to-peer lending to work around this issue, with individuals directly financing “agropreneurs” looking to scale their micro and small agriculture, aquaculture, and livestock businesses. Crowde allows farmers to apply for capital loans related to cultivation, inventory financing, or invoice financing, and for individual investors to fund farmers’ projects and reap returns in the form of a revenue share upon repayment [181]. In addition to individual lenders, Crowde has also been able to attract institutional investors such as the state-owned Bank Mandiri. Rather than dispersing cash to recipients, Crowde partners with agricultural input suppliers to provide discounted supplies to farmers. At the other end of the value chain, Crowde helps link farmers with wholesale and retail buyers for their harvested goods. To date Crowde has received funds from 62,00 lenders, funded 18,000 farmers with more than US $8 million in capital loans, and claims a repayment rate of 97% within 90 days [181].

There is also room to increase international public financing through schemes in accordance with global climate policy frameworks. As per its REDD+ LoA with Norway, in 2010 Indonesia was paid US $100 million up-front for reducing forestry emissions, with US $900 million more to be delivered over the coming 3-4 years, contingent on its progression through a three-stage plan that included the development of a national REDD+ strategy, the establishment of a coordinating agency and an independent monitoring, reporting, and verification institution (MRV) and, ultimately, actual reductions in forestry emissions (see *Policies and Institutions for CSA)* [182]. Though the intention of the REDD+ arrangement was not for Norway to withhold payment while Indonesian forestry emissions continued to rise, that is what happened for nearly a decade. Despite initial setbacks and uncertain long-term success in reducing emissions, the scheme has been cited as a successful example of “non-payment for non-performance” and the stalemate proved that results-based payment agreements pose little financial risk for donors [132]. Additionally, it’s notable that, despite setbacks, Indonesia maintained dialogue and is now due to access the previously agreed finance [183]. These developments may reassure donors that results-based agreements are a secure means of directly investing in the preservation of globally critical natural resources, causing more donors to crowd into this space.

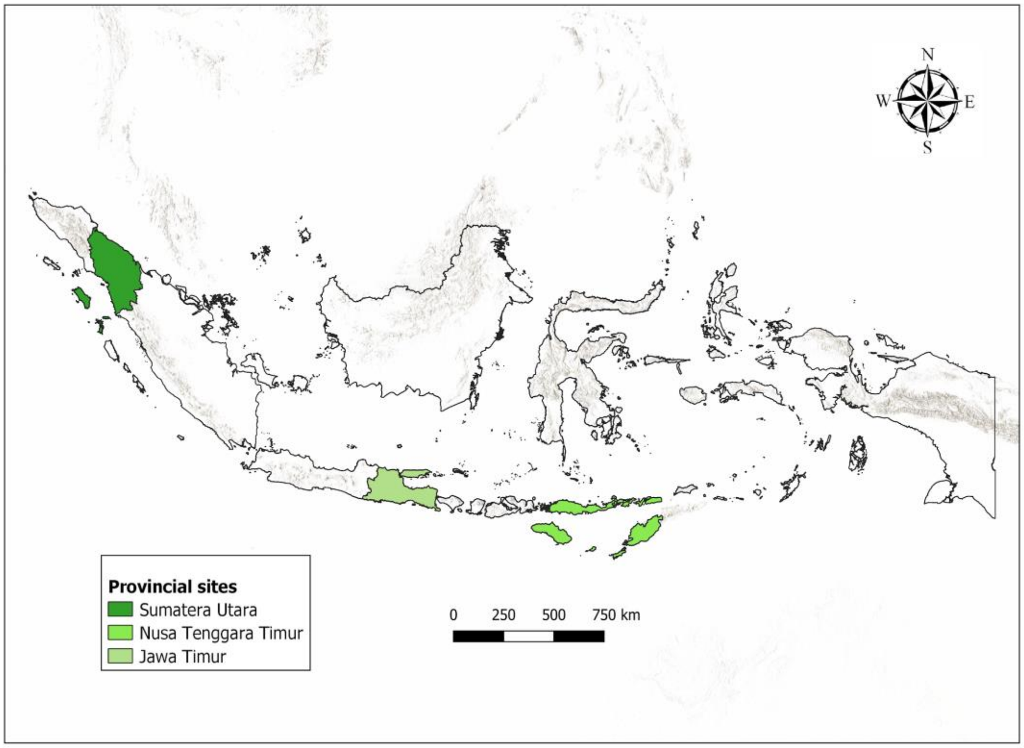
Multilaterally, Indonesia has recently completed the rigorous application process and already received finance from the Green Climate Fund, including more than US $100 million for verified emissions reductions; this cooperation could be expanded to include projects related to CSA [133]. Similarly, only a small portion of the funds Indonesia has received from the Clean Development Mechanism, an emissions trading scheme established by the Kyoto Protocol, were for projects related to CSA [184].

Provincial case studies on climate change impacts and CSA

Site selection

Accounting for Indonesia's vast geography and varying agroecological zones, deep dives into three regions were performed to imbue the national CSA profile with local granularity. In close consultation with the Ministry of Agriculture's Indonesian Agency for Agricultural Research and Development (IAARD,) the provinces of East Java, North Sumatra, and Nusa Tenggara Timur (NTT) were selected to explore the diversity of Indonesia's agricultural production systems. Within each province, a unique set of agricultural commodities, vital to livelihood generation and the local economy, are the result of particular production systems; taken as a whole the three provincial profiles seek to provide a non-exhaustive but broadly representative snapshot of Indonesia's agricultural sector.

Map of provincial study sites



In each province, a series of four-day workshops were convened with support from provincial IAARD staff. The first two days focused on characterizing key farming systems (FS) representative of the province, while the last two days examined the impacts of environmental hazards on the value chains (VC) of two locally-important agricultural commodities from the key farming systems.

Province	Farming System 1	Farming System 2	Value Chain 1	Value Chain 2
East Java	Vegetables, cattle, chicken	Rice, corn, horticulture, chicken, goats	Rice	Vegetables
North Sumatra	Mixed coffee-livestock system	Oil palm, cocoa, rubber, durian, cattle	Arabica coffee	Oil Palm
Nusa Tenggara Timur	Maize, cattle, cassava, legumes	Rice, horticulture, pig	Maize	Pig

East Java

East Java is composed of 431 islands and features a varying topography spanning five agroecological zones. Its expansive lowlands are home to Indonesia's largest wetlands and mangrove forests, more than 2,100 km of coastline, alluvial areas, karstic plains, river terraces, floodplains, plains, and lower volcanic slopes [56]. Its higher-altitude areas are dotted with volcanic hills and mountains with slopes ranging from 15-40%. Temperatures range between 14.0-33.5° C, with an average of 25.1° C, and 1885 mm of annual precipitation [56]. In total, 9% of East Java's lands are classed as being in critical or very critical condition, meaning that due to severe loss of vegetation the land's water retention, erosion control, nutrient cycling, micro climate regulation, and carbon retention abilities have been "completely depleted"[56].

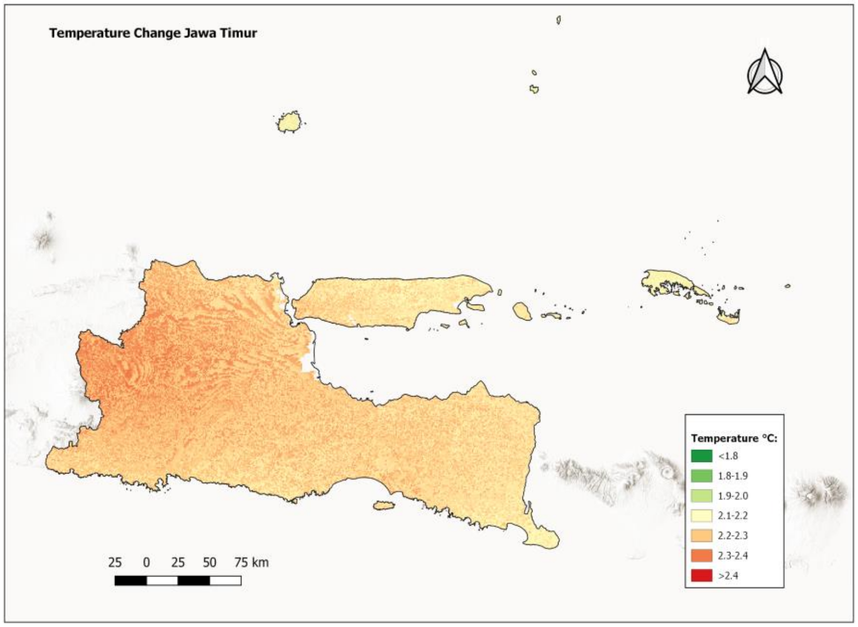
Home to 40 million people, or 15% of the national population, East Java is Indonesia's second-most populous province [56]. Surabaya, the provincial capital, is Indonesia's second-largest city and the region is an economic powerhouse, with wholesale and retail trading, manufacturing, accommodation/food service, and construction as the main industries [181]. While Surabaya and the western areas of East Java are industrialised, the province's eastern portions are more reliant on agricultural production for economic output. Overall, more adults are employed in the agriculture, forestry, and fisheries sector in East Java than in any other province [56]. The average net salary per month for a worker in the sector is 1,523,826 Rp, which is the third lowest of all Indonesian provinces [56]. East Java's human development index is 71.5, with 10.2% of residents living below the national poverty line; though both are roughly average for Indonesian provinces, due to East Java's size it is home to more individuals living below the poverty line than any other province–4.06 million [56].

East Java's diverse landscapes and agroecological zones support a multitude of agricultural production systems, and food crops, estate crops, and livestock all play a key role in its agricultural economy. The province boasts the largest cultivated areas of paddy rice, sugarcane, coffee, cocoa, and tobacco in the country, as well as more heads of beef cattle, dairy cattle, and chicken (native and layer) than any other province [56]. Maize and soybean are also grown extensively, in addition to shallots, chilies, potatoes, tomatoes, and garlic. The province's expansive irrigation infrastructure has supported a huge increase in paddy production over previous decades, which has in turn spurred on growth in the livestock sector where paddy waste (and the byproducts of other crops) is used for feed. East Java is Indonesia's cattle capital[12], and the native *Bali* cattle is reared extensively for its size and local suitability. The province is also home to expansive populations of small ruminants, with the second and third largest provincial populations of sheep and goat, respectively [56].

Workshops for data collection were held in the Malang Regency, East Java's second largest, and included participants in the rice and vegetables value chains from the districts of Bululawang, Junggo, Ngantang, Pakisaji, Poncokusumo, Pujon, Tangkil Sari, Tawangaro, Turen, and Wonosari dan Turen.

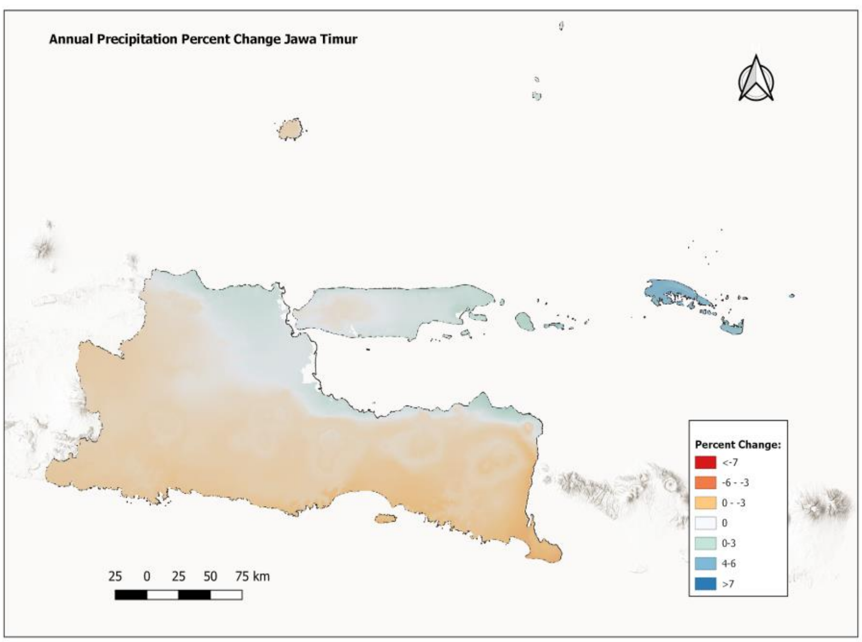
[12] East Java is home to 288 thousand heads of dairy cattle, more than twice as many as Jawa Tengah, which has the second highest population, and 4.8 million beef cattle–nearly triple the population of Jawa Tengah, which again has the second highest population [56].

Temperature Change in East Java (Average 1970-2000 vs. 2050)



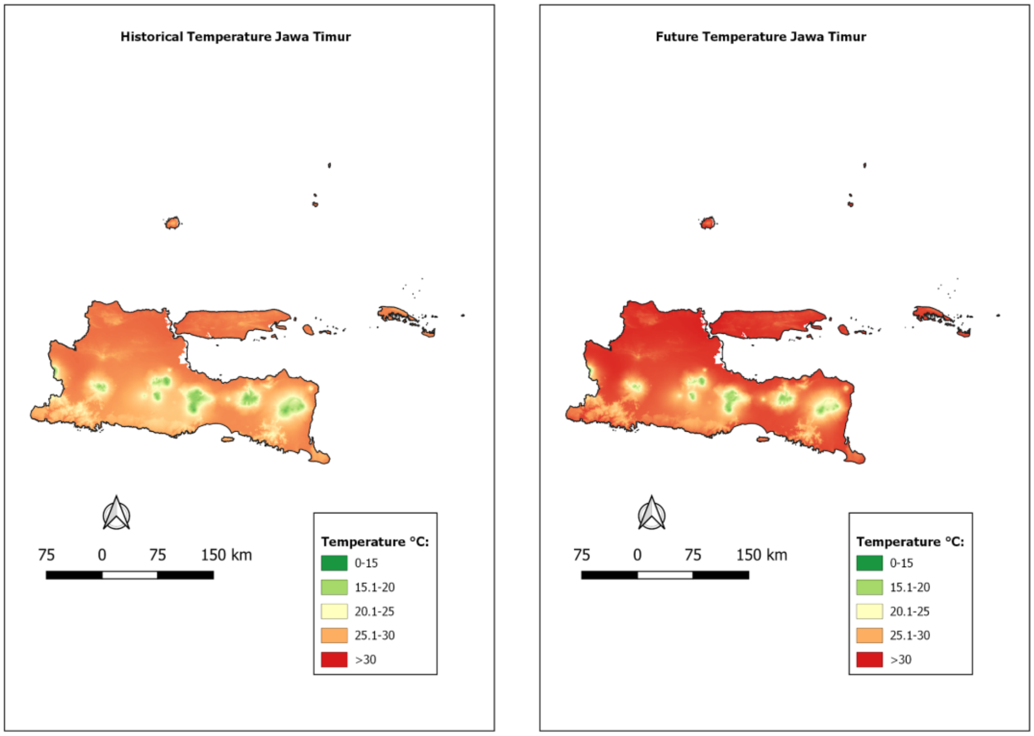
[102,185]

Precipitation Change in East Java (Average 1970-2000 vs. 2050)



[102,185]

Historical (Average 1970-2000) and Future (2050) Temperature in East Java



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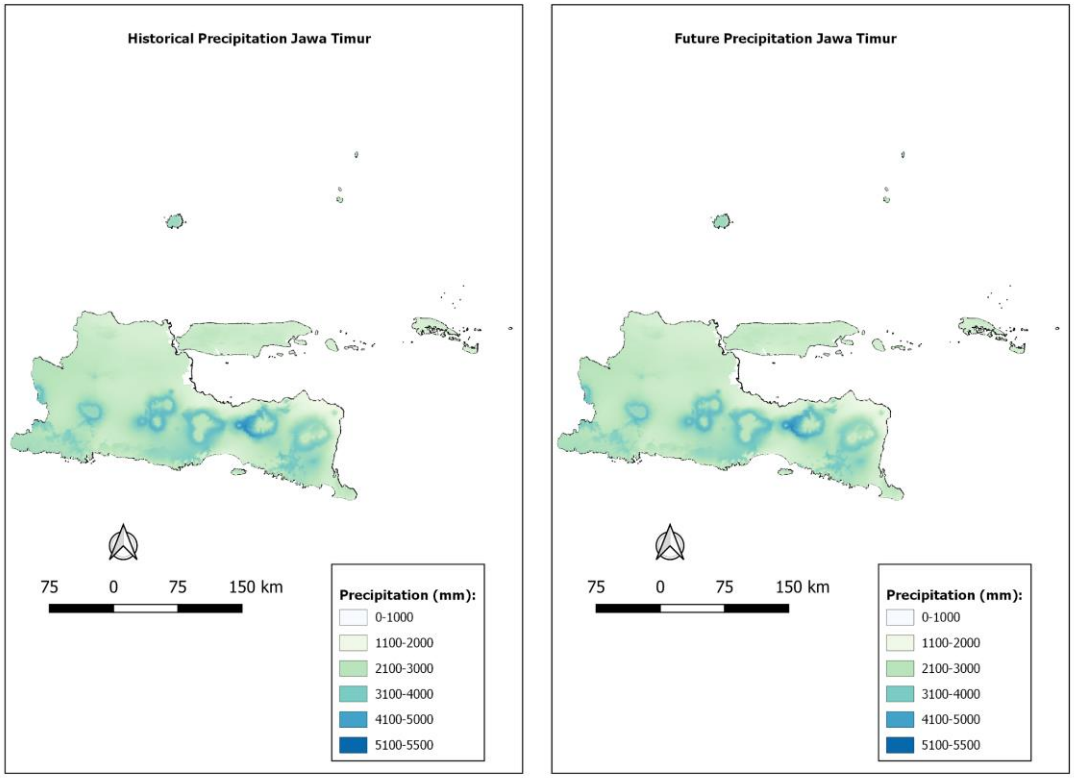
Historical (Average 1970-2000) and Future (2050) Precipitation in East Java



[102,185]

East Java vegetable-based system

General characteristics and resource flows

East Java's vegetable-based farming systems are mainly located in the provincial highlands and are small to medium-scale in size, spanning 0.1-3.5 ha of land area. Most employ crop rotation to produce cabbage, chili pepper, mustard greens, potato, shallot, and tomato, while also rearing poultry and cattle. The average herd size is between two and ten cattle. Vegetable yields range from 8-30 tonnes/ha, and dairy cows can produce up to 15 litres of milk per day. Though some households own their own land, many rent their primary growing areas from other households, or supplement their own with additional plots. Rental schemes are often paid for through profit sharing arrangements. Hired labour comprises 90% of the workforce employed for crop production as members of the household concentrate their efforts on cattle rearing, spending 80% of their time on beef cattle and 20% on dairy cows. Households rent tractors and other expensive production tools for farmer groups, while water pumps and both sprinkler and manual irrigation systems are generally owned and installed by individual farmers. Nitrogen-Phosphorus-Potassium fertilizers (NPK), animal manure, and vegetable waste are applied to all vegetable crops during land preparation throughout the growing season. Cattle are stall-fed with silage, hay, purchased rice husks/straw, and cut-and-carry grass. The main forages fed to cattle in the highlands of East Java include elephant grass, corn, lamtoro (*Leucaena leucocephala*), *Calliandra calothyrsus* and native grass [186]. Elephant grass and corn are most commonly used during the dry season, with elephant grass grown in rice fields, moors, road side, river banks and wildlife reserves, while corn is only grown in rice fields/moors. Poultry are fed rice bran and food waste. Nearly 100% of vegetable and cattle production is oriented toward the local market, while poultry is mainly produced for household consumption. Despite this, poor access to markets further afield and low selling prices negatively impact farmers' incomes. Due to this, most farming households supplement their agricultural incomes with other livelihood streams, with up to 60% of total household income generated by off-farm activities.

Constraints

Farmers indicated a moderate-to-severe level of human, financial, natural, physical, and social constraints on their production. Limited rainfall at the rainy season's offset limits water resources and soil fertility is steadily decreasing due to excessive cultivation without replenishing nutrient exports. Limitations of steep mountain slopes, such as poor soil structure and low water availability/retention, makes them marginally suitable for vegetable production. Generally poor quality road infrastructure limits farmers' ability to rent tractors, water pumps, and trucks, while limited access to credit facilities prevents them from purchasing their own. Farmers also feel that they lack information on innovative technologies and practices, as well as the skills training and market information to capitalize on them.

Climate change impacts at farming system-level

The main climatic hazards facing the vegetable-based farming system are drought, heavy rainfall, high temperature, pests and diseases, and strong winds. Although the Meteorological, Climatological & Geophysical Agency (BMKG) provides weather forecasts, farmers do not rely on them as they are viewed as inaccurate. While these forecasts may be able to predict fairly or weekly weather forecasts, they are often unable to anticipate extreme climatic events. Of these, the most severe are pests and disease outbreaks–powdery mildew and onion maggots in shallots, fungal diseases in potato, and club root disease in cabbage–which often result in a 100% loss of crops when occurring within 40 days of planting. Other impacts include wilting and stunted growth, decreased yields and diminished quality of produce. Bali cattle are vulnerable to heat stress, high humidity, and seasonal weather patterns that lead to reduced feed availability [187]. Drought also often leads to increased instances of parasites (e.g. ticks, flies, worms), disease, and a lack of feed [187].

East Java rice-based system

General characteristics

In the lowlands paddy rice is cultivated exclusively, in intensive systems. In separate upland systems, upland rice is rotated with corn and sweet potato. Elsewhere in the uplands, cayenne pepper, sengon trees, sugarcane, chicken, and goats (jawa randu breed) are produced. Most farms are just 0.1-2.0 ha in size and occupy a mix of privately-owned land, rented land, and communal village-owned land. While some farmers own their own water pumps, hand sprayers, and ploughing equipment, these are often rented from farmer groups alongside heavy equipment like planters, tractors, threshers, and weeding machines. Manual irrigation is applied to all crops except for sweet potato, which is rainfed. Rice farmers with high skill levels tend to manage their own crops, while those with less training rely to a greater extent on hired labour; all other crops and livestock commodities in the system are almost completely reliant on hired labour. Urea is the most commonly used chemical input for rice, Petroganik, an organic fertilizer, is more commonly used for rice and sugarcane, and manure for corn and chili peppers. Demand for fertilizers, pesticides, and herbicides vary seasonally and, though the rollout of the national Farmer's Card programme was meant to facilitate access to these inputs, just 5% of local farmers have received their cards.

Chicken are mainly fed rice bran and husks, and are allowed to roam within enclosures in the farm. Goats are fed via a combination of open grazing, tethered grazing, and stall feeding with collected fodder consisting of a mixture of shrubs and leaves from banana, cassava, maize, coffee, elephant grass, *Calliandra calothyrsus, Leucaena leucocephala,* and *Gliricidia sepium*. By-products from the system are mainly recycled back into the farming system: rice straw is utilized for livestock feed, while chicken and goat manure are either applied to the land or sold to other farmers. Small scale farmers generally consume two-thirds of the rice they produce and sell onward a third for profit. Large scale farmers produce rice exclusively for profit. Goats, corn and sweet potato are exclusively market-oriented, while chickens are exclusively produced for home consumption. Farmers are generally satisfied both with their access to markets, and the prices they receive. Nonetheless, more than 80% of small scale farming household incomes are generated by off-farm activities such as retail (groceries, clothing) and employment in the civil service.

Constraints

Farmers in the rice-based production system face a variety of production constraints. Waste water polluted with plastics flows through farms, severely damaging crops–particularly paddy rice. While an irrigation canal from a nearby factory was recently shut off for this reason, its loss also increased water stress in the community. The long-term excessive use of chemical inputs has also increased the susceptibility of crops to pests and diseases and the need for evermore fertilizers and pesticides. Soil acidity resulting from excessive mineral fertilizer application, and leaching leads to losses of up to 80% of rice and chili pepper, 60% of corn, and 30% of sweet potato. Water stress is also an increasingly critical issue as local changes in land-use–the conversion of forests and shrub land to agricultural land, urban expansion, and industrial development–have reduced the water supply for irrigation, while wrangling between government agencies delays the repair of damaged irrigation pipelines. Producers also suffer from wide fluctuations in pricing for vegetables and, while rice prices are more stable, poor quality roads disrupt transportation and limit market access for both. Agricultural human resources are a critical issue and affect productivity in several ways. A lack of extension officers reduces the training available for local producers, and restricts access to improved practices and advanced technologies. Limited youth employment in the sector limits the uptake of climate-smart innovations.

Climate change impacts at farming system-level

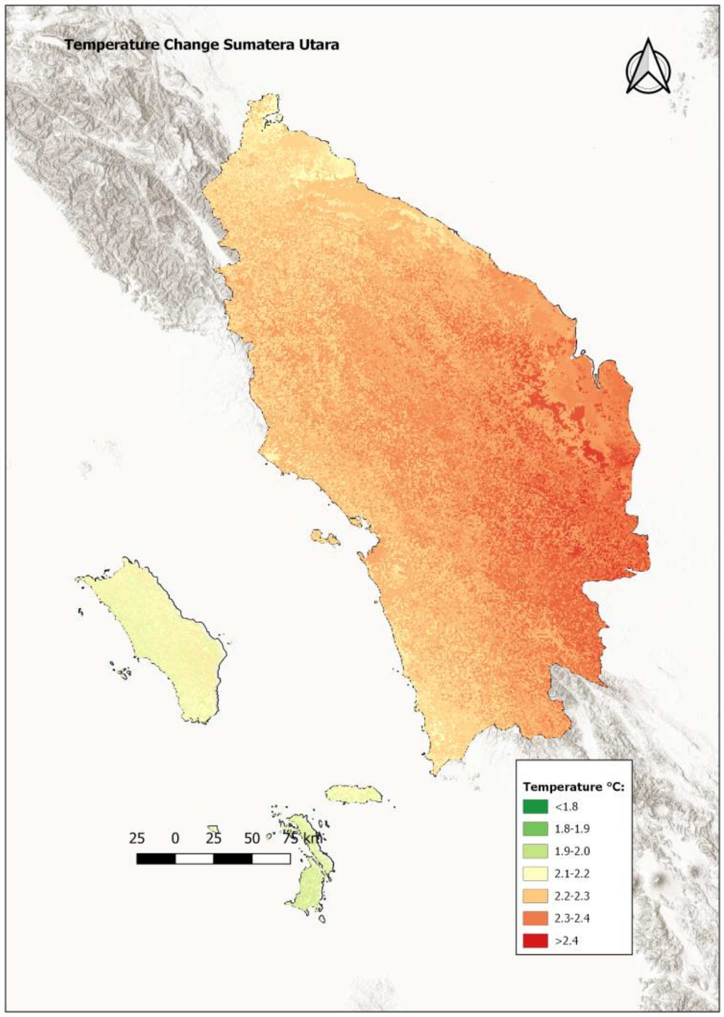
Though pests are the most severe climatic hazard faced by farmers, (with increasing frequency in the past decade), soil acidity, high temperature, heavy rainfall, drought, flooding, and disease (listed in decreasing severity) are all endemic. It is common for pests to lead to complete crop failures of rice and corn, and up to a 25% reduction in yield for chili pepper. Drought, high temperature, and heavy rainfall primarily impact rice and chili pepper, leading to losses of between 20% and 100%. BMKG provides weather forecasts, advice about likely pest and disease outbreaks, and soil test reports to local government offices, who then relay the information to farmers. Goat productivity is mainly impacted by heat stress and high humidity causing animal stress, dehydration, decreased feed availability, and reduced body weight [188].

North Sumatra

North Sumatra has a population of 14.6 million spread across 232 islands and 730,000 km² [56]. Its varying elevation consists of both lowland flatlands and mountainous uplands, and features a diverse topography. The province has a rainy season running from September through April, and a dry season from May through August [189]. In 2018, North Sumatra received 1,884 mm of rain on 172 rainy days, and had a 55.4% duration of sunshine, and temperatures ranged from 21.0 - 36.2°C with an average of 27.4°C [56]. North Sumatra is home to more land classed as being in critical or very critical condition than any other Indonesian province–13.4 thousand km²–which comprises 18.4% of total provincial landmass [56].

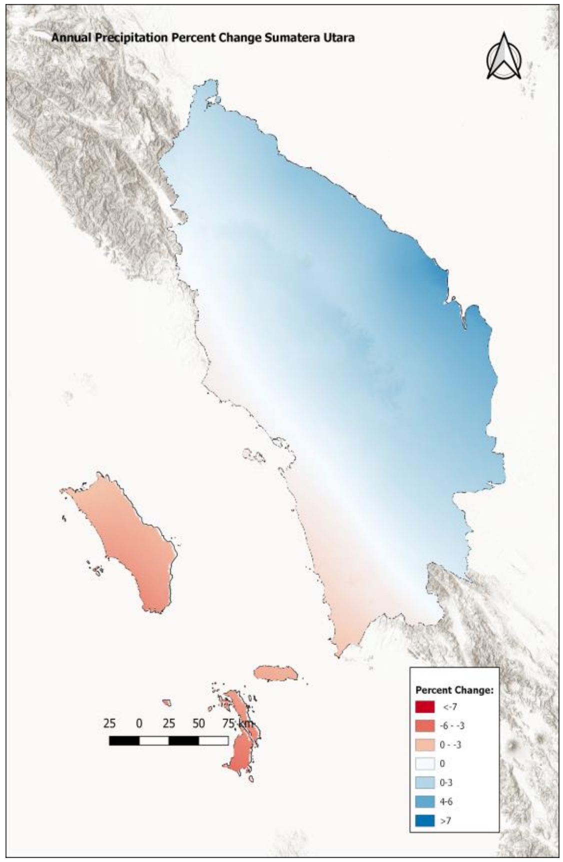
Agriculture, forestry, and fishery is the largest economic sector in North Sumatra, contributing 24.8% of total gross regional domestic product (GRDP). Though the key food crops in North Sumatra are paddy rice and maize, estate crops are important to the provincial economy. North Sumatra is the second largest rubber-producing province in Indonesia, and the third largest for coconut and oil palm. However, poor agricultural practices (over-application of chemical fertilizers and pesticides, mismanagement of livestock waste, and intensive usage of groundwater supplies) and deforestation (due to farming extensification and land-use change) are threatening the long-term productivity of the province's agricultural sector while increasing GHG emissions. Extreme weather is also a growing threat, with floods, droughts, and saltwater intrusion endangering agricultural, and particularly coastal, communities.

Temperature Change in North Sumatra (Average 1970-2000 vs. 2050)



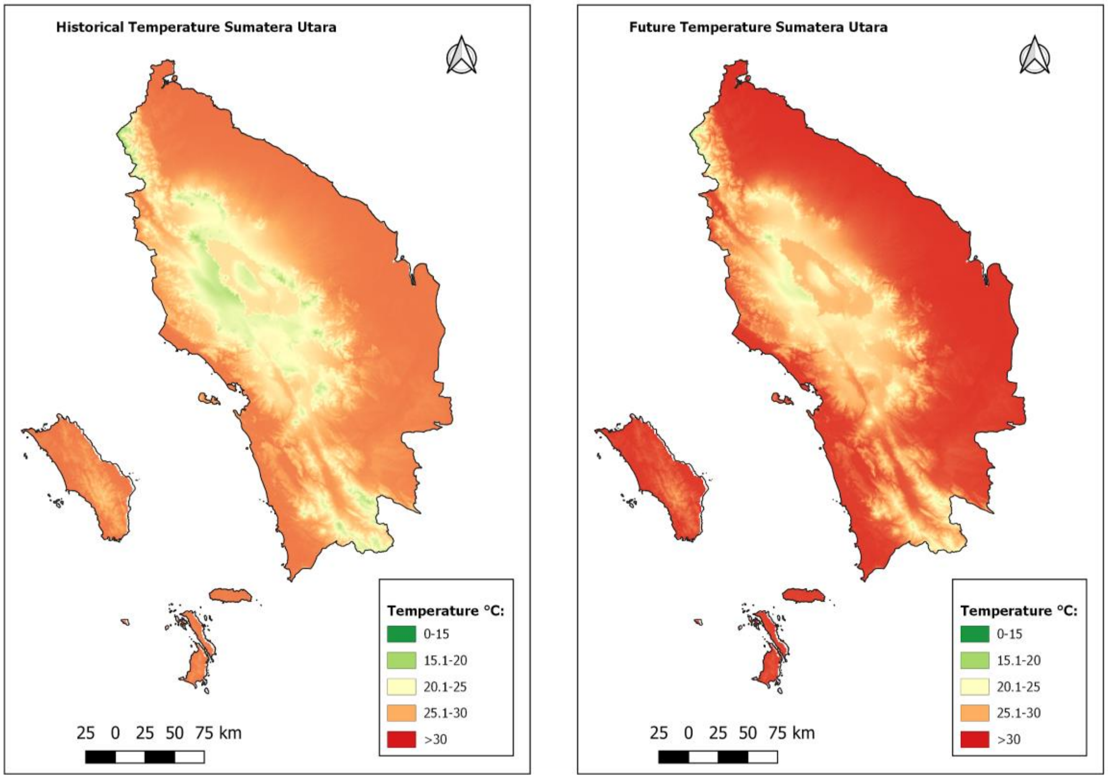
[102,185]

Precipitation Change in North Sumatra (Average 1970-2000 vs. 2050)



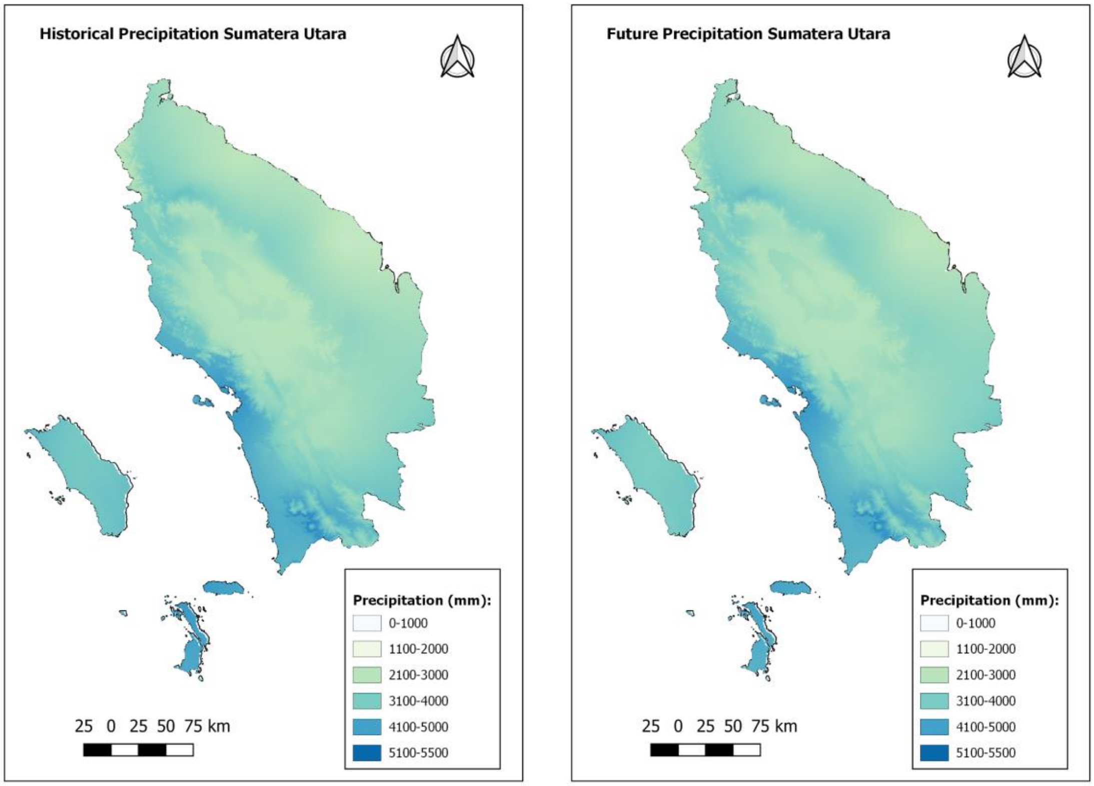
[102,185]

Historical (Average 1970-2000) and Future (2050) Temperature in North Sumatra



[102,185]

Historical (Average 1970-2000) and Future (2050) Precipitation in North Sumatra



[102,185]

Mixed coffee-livestock system in North Sumatra

General characteristics and resource flows

Coffee farms in this system are mainly owned by individual households on plots ranging from 0.2-1.5 ha. Coffee comprises up to 75% of agricultural land in addition to maize (10%), cavendish banana (5%), and oranges (5)%. Chicken is the main livestock raised in this system; the average home owns approximately 170 birds. Most farm work is performed by members of the household, except during harvesting of coffee, chili, orange, and honeybee, when hired labour is also employed. While hybrid varieties of coffee and maize are often cultivated, local varieties of banana, chili, orange, and turmeric are more common. For fertilization, urea is only used for maize and coffee, the latter of which also benefits from the application of coffee residues, maize stalk, and chicken manure. Chicken are mainly the hybrid Kampung Unggul Balitbangtan breed, which are locally-suited and produce a high quantity of eggs [190]. Though they are disease resistant, they still receive routine vaccinations and are fed a mixture of homemade cassava-based and store-bought feed. Honey bees are left to breed naturally and feed freely on Calliandra flowers. Farmers are generally able to access the inputs and are satisfied with the prices paid for their goods at market.

Most agricultural production in the coffee-based farming system is market-oriented. Coffee trees yield roughly 1 kg of green beans per tree per year or 2 kg of ripe red cherry beans per season per ha, and are exclusively sold. Though green beans fetch a higher price at market, most farmers prefer to sell cherry beans as there is less labour involved in their production and harvesting. Orange and chicken are also sold onward, while 80% of maize and 60% of banana are produced for marketing, with the remaining portion used for home consumption. Revenue from agricultural production is often supplemented by off-farm activities, which can account for up to 50% of total income.

Constraints

A wide variety of constraints restrict the productivity of North Sumatra's coffee-based farming systems. Heavy rainfall damages the flowers of coffee, chili pepper, and banana crops, often leading to failure, while soil erosion and landslides complicate crop maintenance, harvesting, and transportation. Though inputs are generally accessible, limitations remain in sourcing certified seeds, subsidized fertilizers, and expensive cultivation equipment like lawn mowers and augers. A lack of engagement with extension services, which are scarce, has impacted the uptake of improved cultural practices and technologies, and many cooperatives that could potentially fill this gap are now defunct. This has limited skill development and innovative capacity, and many farmers call for additional training venues, education on new and improved technologies, and GAP training and certification. Farmers can struggle to market what is harvested due to poor quality road infrastructure. Ultimately, farmers in the coffee-based system depend on off-farm income for their livelihoods, which limits the amount of time available for maintenance of coffee trees. This deficiency is exacerbated by a lack of productive capital, as most farmers are not able to access credit facilities due to a lack of collateral.

Climatic impact at farming system-level

Climatic hazards in North Sumatra are less severe than those in East Java and NTT and tend to occur with predictable seasonality. Drought is the most severe, often lasting from March through September, and can result in lost yields of up to 40% as flowers on fruit crops become damaged and fruits fall from trees prematurely. Heavy rainfall during the rainy season, from August through October and peaking in July, also causes crop damage and delayed harvests, resulting in up to a 40% loss in yields. Pests attack crops year round, although most severely in June, July, and December, with coffee berry borer *(Hypothenemus hampei)* and mosquito *(Helopeltis sp.)* reducing coffee yields by up to 40%.

Oil palm-based system in North Sumatra

General characteristics and resource flows

The oil palm farms in this system typically range in size for 1-6 ha and are owned by the households that use them for production. Oil palm (both Marihat and local varieties) are cultivated on 60-100% of available farmland, with rubber, cocoa, durian, and maize grown on the remainder. Cattle are also reared in this system, and often allowed to graze on oil palm fields to control weeds and fertilize the soil. Despite oil palm's profitability, much of production is performed with simple equipment, such as digging hoes, knives for cutting palm fruit, trolleys, and hand sprayers. Tractors are rented from farmers groups at a rate of approximately 50,000 IDR (US $3.48) per 400m^2. Household labour is predominantly employed for crop and livestock production, except during the pruning and harvesting of oil palm and tapping of rubber trees, when hired labour is also brought. Chemical fertilizer (urea) is applied to oil palm at rates of 100-150 kg/ha, as well as to young rubber trees, banana, and turmeric. Cocoa trees used to be present in this farming system but are no longer maintained by farmers; most have been replaced with oil palm, which requires significantly less post-harvest processing. Cattle are either grazed freely or within the oil palm plantations, and are injected with vitamins to boost their immunity. Breeding is performed with both insemination and artificial insemination, the latter of which costs approximately IDR 300,000 (US $20.88) per instance.

Nearly all production is market-oriented, with 100% of oil palm, rubber, cocoa, and cattle, 80% of durian, and 95% of maize sold at market. Roughly 5% of durian and 20% of maize are kept for home consumption. Residues from the primary products play an important role in systemic productivity as they are fed back to the system. For example, 100% of oil palm residues (empty fruit bunches, kernel shells, and leaves) are mulched back to the oil palm plantations. Maize stalk is fed to cattle and cow manure, in turn, is applied to the oil palm fields. While high quality oil palm seeds and subsidized fertilizer can be difficult to access, pesticides are relatively cheap and easily accessible. Marketing opportunities are readily available and sale prices generally high, with farmers enjoying satisfactory profit margins–especially on oil palm. This is their main source of income, with less than 5% of farmers supplementing their on-farm incomes by running small businesses such as cafeterias.

Constraints

A combination of heavy rain and hilly topography leads to high levels of fertilizer runoff, increased fruit fall, loss of taste in durian and banana, and rubber sap mixing with water. These challenges lead to increased crop management costs, particularly for oil palm and rubber. These costs are heightened by poor road infrastructure, particularly for remotely-located oil palm farms, costly cultivation equipment, with augers costing approximately IDR 10 million per unit (US $702.20), and limited quantities of certified seeds and subsidized fertilizers. However, oil palm farmers report very few financial, social, or human resource-related constraints. Given oil palm's profitability and ease of marketing, informal finance is widely available. Information and advisory services are provided through an abundance of extension services, farmers tend to be highly skilled, and information is easily accessed through internet-based sources.

Climatic hazards and impact at farming system-level

While the main climatic hazards for oil palm farmers are high temperature, heavy rain, and moderate drought, their impacts are mild when compared to those in other local farming systems. Drought mainly impacts maize in January and February by stunting the growth of young plants, reducing yields by 5%, and damaging roads, which leads to an increase in transportation costs. Heavy rains often occur in August and September, toppling oil palm trees, inducing soil erosion, and also damaging roads, thus increasing transportation costs.

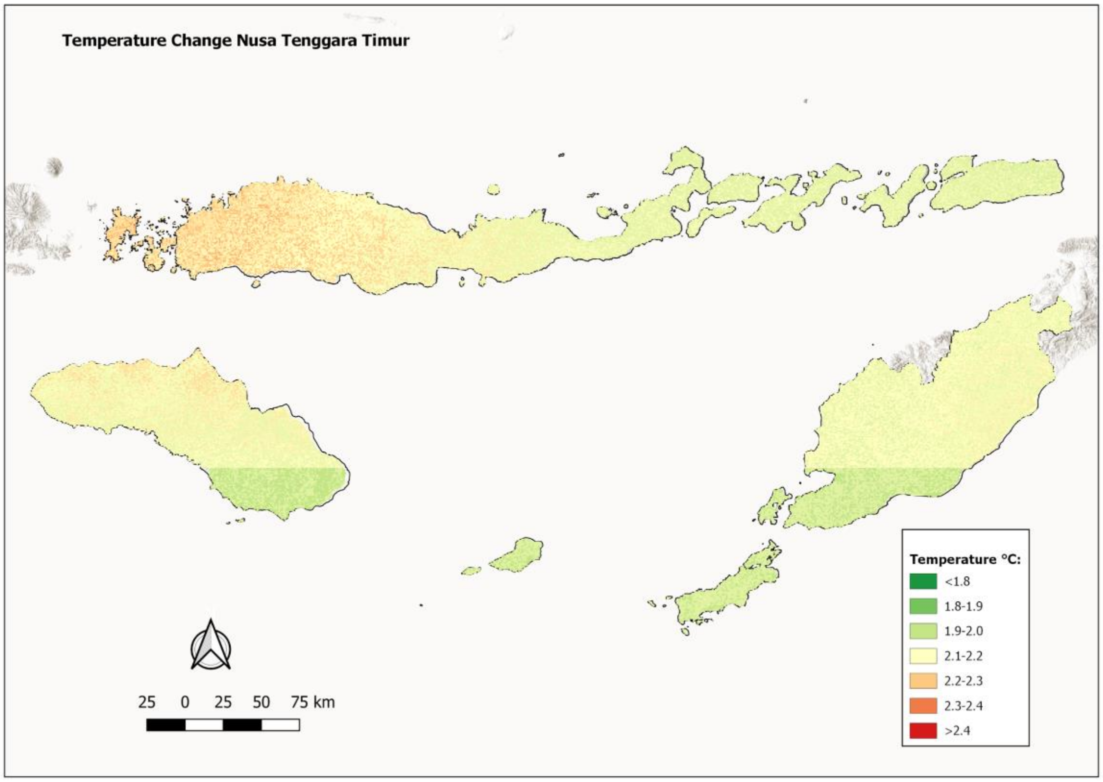
Nusa Tenggara Timur

Nusa Tenggara Timur (NTT) is home to 5.5 million inhabitants spread across 48.7 thousand km² and 532 islands [56]. Despite its coastal setting, NTT has a semi-arid climate and is one of Indonesia's driest provinces. In 2019, it received just 955 mm of annual precipitation (third least) during 84 days of rain, the least of all provinces[56]. The province's dry season spans most of the year, from April through November, and allows for just a single paddy crop per year during December-March. In NTT, 17.3% of land (8.4 thousand km²) is classed as critical or very critical [56].

Agricultural production comprises 23.5% of GRDP and is critical to livelihoods as well as food security and nutrition. Approximately 72% of households rely on small-scale agriculture for income generation and subsistence, particularly of rice, maize, and tubers, is widespread [191,192]. Overall, NTT has the lowest per capita GRDP of all provinces, as well as the lowest mean monthly salary for formal workers in the agriculture, forestry, and fisheries sector (IDR 1,395,177 or US $99.00), and the second lowest mean monthly salary for informal workers in the AFF sector (IDR 905,218 or US $64.23) [56]. NTT's HDI is 65.23, the lowest of all Indonesian provinces, with 20.6% of residents living below the national poverty line–the third highest rate in Indonesia [56]. Such economic hardships manifest as food insecurity, with NTT's population having the highest per capita month food expenditure (62.3%) of all provinces and the lowest daily average per capita calorie and protein consumption (53.8g) [56].

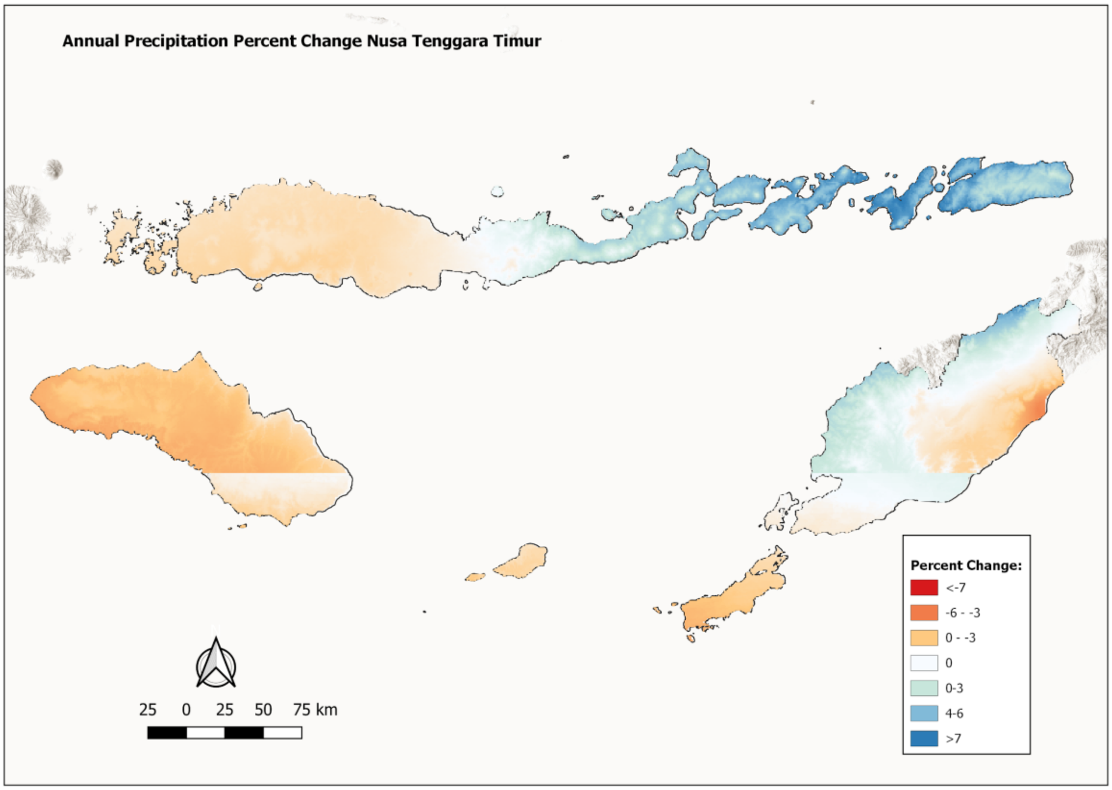
Agriculture in NTT is largely characterised by traditional, low-productivity cultural practices. Productivity growth is further constrained by financial hindrances, an insufficient labour supply, and a lack of requisite infrastructure such as rural roads and irrigation systems. Rice, maize, and mungbean are the primary food crops produced in NTT, and coffee, cacao, cashew, and clove are the dominant estate crops. Horticultural production is also common and largely oriented toward local markets. Given NTT's semi-arid climate, livestock production is a vital agricultural sub-sector. More buffalo (175 thousand heads) and pigs (2.4 million heads) are reared in NTT than in any other province [56]. NTT is also home to more than one million heads of cattle, making it the fifth-largest cattle rearing province [56].

Temperature Change in Nusa Tenggara Timur (Average 1970-2000 vs. 2050)



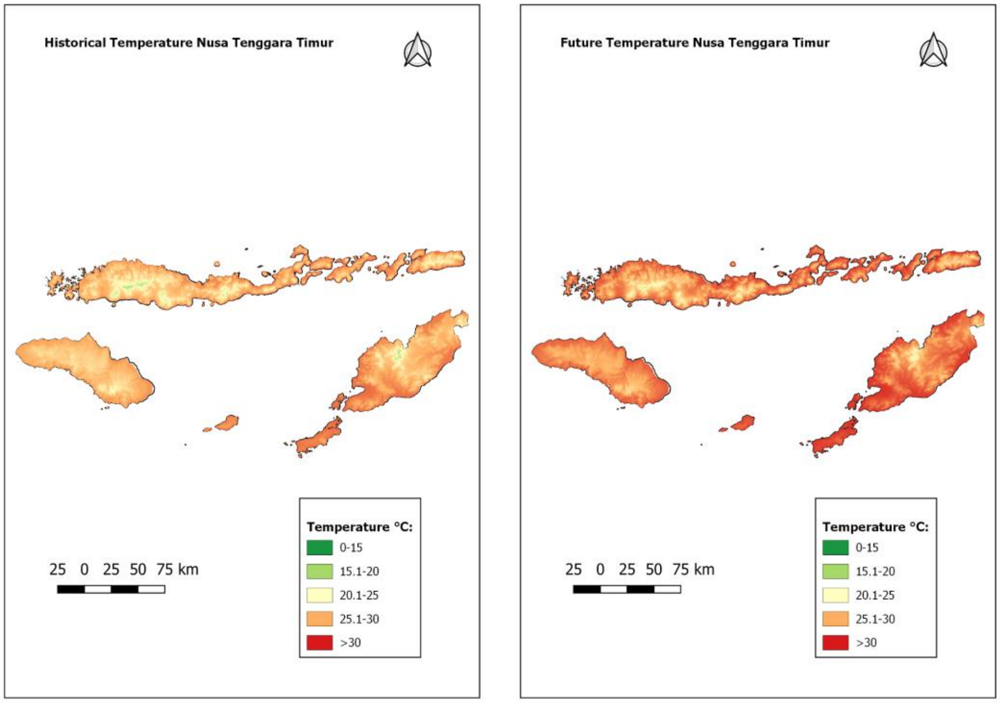
[102,185]

Precipitation Change in Nusa Tenggara Timur (Average 1970-2000 vs. 2050)



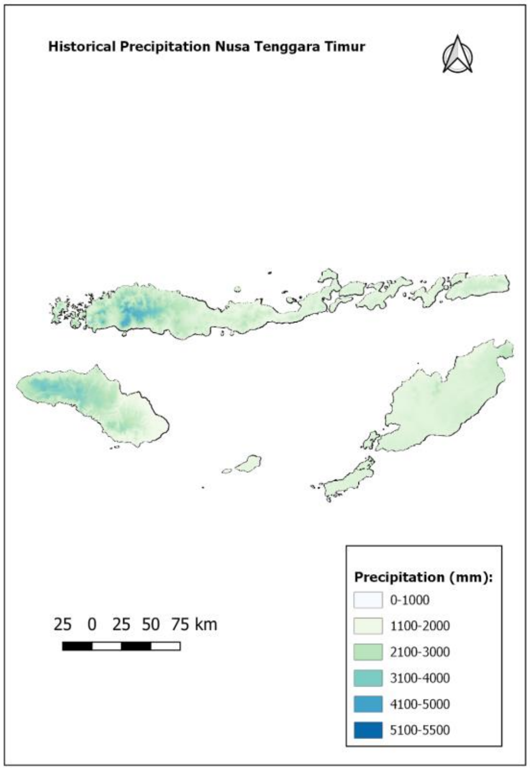
[102,185]

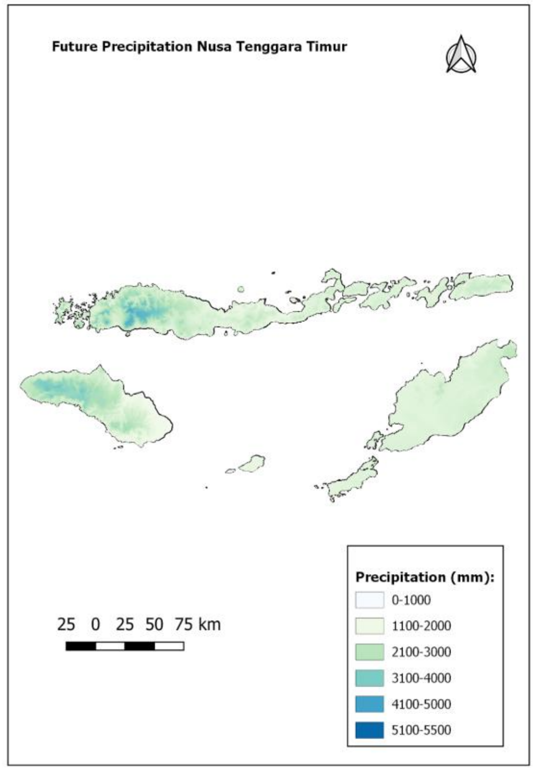
Historical (Average 1970-2000) and Future (2050) Temperature in Nusa Tenggara Timur



[102,185]

Historical (Average 1970-2000) and Future (2050) Precipitation in Nusa Tenggara Timur





[102,185]

Integrated maize-cattle system in Nusa Tenggara Timur

General characteristics and resource flow

The integrated maize and cattle farming system is characterized by farms ranging from 0.1-5 ha in size, with maize grown on between 80 and 100% of agricultural land, recording yields of approximately 2 ton/ha for local variety, 4-6 ton/ha from Lamuru variety and 6-7 ton/ha for hybrid varieties. Cassava, rice bean, pumpkin, pigeon pea, tomato, and shallots are grown on 10-20% of land, while cattle, goats, pigs (with an average herd size of 2-4 animals per household), and local chicken are also reared. A majority of farmland is owned by individual households who own their own light farming equipment and work their own crops and livestock. Most rent heavy machinery, like tractors and large water pumps, from the local government and some households rent additional land for farming. Cooperatives are also active in the area, owning their own land and equipment which is distributed amongst members. Crop production is mainly rainfed with supplemental irrigation during the dry season. Chemical fertilizers (urea and NPK) are applied to maize and rice bean only at a rate of 100-150 kgN/ha. Artificial insemination and vaccination are widely used for cattle, though significantly less-so for pigs. Cattle are either grazed on native grass or stall-fed with crop residues and collected feed (*Leucaena glauca*, *Gliricidia sepium*, banana stem, collected grass, turi nut, and fermented putak from oil palm stalk). Poultry are mainly fed corn while pigs eat food waste, purchased concentrates, and stems of gebang palm. Maize yields range from around 2 tonnes per ha for local varieties to 4-7 tonnes per ha for hybrid varieties. Harvested maize is sun-dried, shelled, and destined for a variety of uses: approximately 40% is for household consumption, 40% used for livestock feed, 10% for sale, and 10% kept as seed for the next crop cycle. Maize used as livestock feed is mainly fed to chicken and pigs, though a small amount may be used for cattle as well. Rice bean and pigeon pea are mainly produced for household consumption, while pumpkin and cassava are variously consumed by households, turned into feed for livestock, and used for seed. Cattle are grazed in the fields after harvest, and manure is disposed of in the environment without being treated. Some manure is used for bokashi– a nutrient cycling process similar to composting which uses bacteria rather than decomposition to break down organic matter, and retains nearly all carbon, energy, and nutrients in the final product [193]. Livestock production is mainly market-oriented, with more than 90% of animals, apart from chicken, sold at market. Market access is an issue at both ends of the production cycle: fertilizers, high quality seeds, and planting materials are difficult to source and, while markets for selling farm produce are available, low sale prices yield little profit for most farmers. Producers also struggle to supplement their agricultural incomes with off-farm employment. Though many producers moonlight as drivers, construction workers, food stall workers, market retailers, rice millers, and local administrators, just 10-20% of total average income is derived from off-farm economic activities.

Constraints

Clayey soil, hilly topography, erratic rainfall, and soil erosion complicate efforts to plough the land and reduce yields of all crops. Soil type and topography also contribute to bad quality roads, which limit market access. A lack of training and information related to agronomic practices like pest and disease control, cultural practices, and business development, combined with severely restricted access to credit (due to a lack of loan collateral) make it a challenge for many small producers to scale their businesses and limit the profitability of all commodities produced in the farming system.

Climatic hazards and impact as farming system-level

NTT's location in Indonesia's drylands makes it highly susceptible to drought and high temperatures. Drought here is caused by decreases in rain intensity, shortened duration of the rainy season, and unexpected changes in rainfall patterns. The changes are felt most acutely during the dry season, between May and December, and manifest as decreased production or total crop failure, with yields of most crops declining between 60 and 100%. Heavy rains, flooding, and soil erosion make the rainy season, between January and June, similarly hazardous, although crop damage and reduced yields are less pronounced at between 5 and 10% for most crops. Pest and disease outbreaks lead to 20-50% reductions in maize yields. High temperatures, which are intertwined with pest and disease outbreaks, make it difficult to access feed and water for livestock, causing reduced weight (up to 30%) and death (up to 10%). Livestock production in NTT mainly relies on unimproved native grassland that are severely impacted by prolonged periods of drought. These, in turn, cause a significant decline in high quality pasture and subsequent feed scarcity, resulting in weight losses of up to 0.2-0.5 kg/head/day depending on the age of the animals [194,195]. In severe cases, starvation leads to death [194,195]. The impacts of all climatic hazards are worsened by a lack of forewarning, as farmers lack information services that would allow them to preempt hazards and mitigate their worst effects. Though BMKG provides weather forecasts before planting seasons, farmers tend to discount them as they believe the information is not accurate.

Rice-horticulture-pig system in Nusa Tenggara Timur

General characteristics

Most operations employing a rice, horticulture, and pig-based farming system in NTT are small-scale, occupying between 0.1 and 3 ha of land, and farmer-owned. Rice is cultivated on 80-90% of land and is grown in rice-rice, rice-vegetable (cabbage, long bean, tomato, eggplant, mustard green, kale, chili), rice-corn, rice-fallow, and corn-fallow rotations. Barn pigs (roughly three per household production system and 90 at commercial scale), cattle (average herd size of 1-20 cows per household), chicken, ducks, and goats are also reared. Production equipment is either owned by farmers or leased from the government. Given the area's lack of precipitation, irrigation water sources play an important role in crop production. Crops are worked mainly by hired labour, except for the corn-fallow season, when household labour is mainly employed. Apart from commercial-scale pig farms, who outsource roughly half of their labour requirement, most small farms in this system produce pigs mainly for home consumption rely on household labour.

Cattle, goats, and poultry are also overseen by members of the household. Hybrid rice varieties are commonly used and result in yields between 8 and 16 tonnes per ha. Both inorganic (urea, NPK) and organic fertilizers (Petroganik) are applied to crops. Pigs are mainly fed with concentrates and food waste while chicken are allowed to roam freely within the farm. A majority of small farmers graze their animals on native grass and local legumes in communal grazing areas, while improved grasses (elephant and king grass) are grown by a few large farmers. With grazing areas decreasing over time, animals are often tethered or stall-fed using forages collected from rice bunds, road sides, irrigation channels, river banks, and neglected land. This "cut-and-carry" feeding is more common in the dry season, when grass is hard to come by and farmers rely on crop residues to a greater degree. Sesbania is the most commonly grown forage legume in NTT while Leucaena and Gliricidia are grown and fed to cattle in a few areas [196]. All livestock species are vaccinated and pigs are commonly conceived using artificial insemination, while natural insemination is more common for cattle. Some farmers grow corn as fodder. Rice straw and husks and corn residues are also fed to livestock, with the excess sold to other farmers. Manure from livestock is both applied to the land as fertilizer or used for biogas production. Between 70 and 100% of crops and livestock produced are for sale, with approximately 20% of pigs and rice and 19% of vegetables held back for household consumption. Despite high market access for both inputs and outputs, low market prices restrict producers' profit margins. Profitability issues are also linked to the IJON system of rural credit, whereby farmers use crops as loan collateral [197]. Off-farm income sources irrigation services (15%), rice milling, and taxi driving.

Constraints

Environmental issues such as limited water resources, soil infertility, and pest and disease outbreaks routinely result in reduced yields, total crop failure, animal weight loss, and livestock deaths. Pig housing and sanitation practices are often inadequate which, coupled with the high cost of concentrated feed, severely impacts pig production. African swine fever (ASF) has also severely impacted local pig populations, diminishing production by 70-100%. Financial constraints also limit farmers' ability to hire additional labour and access credit schemes, forcing them to rely on the IJON credit system, in which they sell their produce to collectors before it has been harvested, to access loans. The limited availability of extension services and low managerial capacity of cooperatives results in low adoption rates for innovative technologies. Scarce water resources result in social tension and non-violent but sustained conflict, and pig theft is common. Given the lack of protection and insurance mechanisms, producers prefer low-risk rather than high value production. This hesitancy to invest, along with a lack of formal education and business training, limits enterprise development and commercial growth. Additionally, many local youths seek out non-agricultural employment, which saps local businesses of catalytic actors.

Climatic hazards and impact at farming system-level

The main climatic hazards facing producers are drought, heavy rainfall, high temperatures, and increasing salinization. Drought severely impacts yield and results in the failure of all crops in the production system, with recorded losses between 40-100%. In 2020 alone, 500 ha of local land could not be cultivated due to prolonged drought conditions. Drought-induced crop failure also results in diminished feed supply for pigs, leading to the death of up to 10% of the local population. Rainfall is most severe between January and April, and often occurs in combination with flooding and strong winds. These hazards disrupt the pollination of young rice, maize, and vegetables crops, while toppling more mature plants. Combined losses are often between 20-30%. Floods are a particular threat for pig production, as pens flood and pigs drown, causing losses between 30-100%. High temperatures create ripe conditions for pest outbreaks, enabling thrips to destroy 60% of vegetable crops. However, pest and disease outbreaks also occur during the rainy season (February-May), affecting rice and corn especially. Though general climate information is available to farmers, location-specific information and advisory services related to climatic events are not. Occasional information and advisory services come from extension officers and private sector service providers. Pig farmers in particular are keen to receive more detailed advisory services, especially related to ASF.

Recommended Provincial CSA Intervention Packages

1. Promoting the System of Rice Intensification (SRI) in East Java

Rice production is critical to Indonesian food security and can be scaled up by combining traditional and contemporary cultural practices with improved inputs and extension services, additional local processing capacity, and reform of the national fertilizer subsidy.

In East Java, improved on-farm production practices are key to growing rice yields. The System of Rice Intensification (SRI) involves the early transplanting of seedlings, a shallow and sparse planting pattern, and intermittent irrigation [198]. It has been shown to significantly reduce watering by up to 42% and increase yields by up to 78% without the use of additional chemical or technological input, although increased labour requirements have limited adoption [199]. SRI nicely complements the local Jajar Legowo cropping system, in which rows of planted rice are alternated with fallow rows. This wide spacing provides additional space for optimal crop management (fertilizer application, weeding, etc.), resulting in larger yields and higher quality rice. The combination of SRI and Jajar Legowo techniques, particularly when used with caplak planting tools (wheel ticks) to increase labour efficiency, has been shown to increase rice yields in Indonesia by 49% (from 900 kg per 1000 m^2 to 1337 kg per m^2) and improve labour efficiency by more than 18% [200,201]. While SRI requires increased labour inputs, these can be largely offset by mechanization. For example, the Indo Jarwo Transplanter 2:1 has been shown to reduce labour by 78% and overall paddy planting costs by 72% [202]. SRI has also been shown to decrease the global warming potential (tons of CO2-eq produced) from rice paddies by up to 46% in Indonesia through the application of alternate wetting and drying [199]. As rice is both critical to food security and a major source of agricultural emissions, this increased mitigation potential is notable.

Employing precision agriculture (PA) can further help farmers determine input levels according to site-specific information and generally results in reduced input use (thus minimizing costs and environmental degradation) and labour requirements [203]. To enable PA, the International Rice Research Institute, in partnership with local agricultural research institutes, has developed a simple smartphone application to help Vietnamese rice farmers utilise an integrated crop management system [203]. A system of this sort could be adapted to enable Indonesian farmers to apply inputs according to each plant's specific nutritional needs, rather than cost. The use of biopesticides should also be promoted for natural pest and disease control.

Urea deep placement (UDP) can easily be integrated with PA, and has been shown to significantly increase yields while reducing input costs, and is a "low-hanging fruit" for fertilizer efficiency that can be implemented and scaled rapidly. By implanting nitrogen briquettes deep into the soil (7-10 cm), near the root of the rice plant, as opposed to broadcasting across the paddy surface, UDP results in increased nitrogen use efficiency and decreased runoff [204]. Compared to broadcasting, farmers who switched to UDP in Bangladesh have seen yields increase by up to 25%, urea expenditures decrease by one-third, and runoff levels drop from 35% to 5% [204]. A similar case study, also in Bangladesh, resulted in 61-84% lower N_2O emissions compared to broadcasting [205] This is attributed to the decreased supply and conversion of inorganic N substrates to N_2O on the soil surface or in floodwater, as N is retained in NH_4^+ form at a reduced zone (7-10 cm depth) through UDP.

These improved on-farm practices should be facilitated by improving the quality of inputs and extension services available to producers. At base level, the research and development of improved seed varieties should be spearheaded by IAARD and the private sector. INPARI 32 and INPARI 42 are the standard rice varieties subsidized and distributed by the government, while approximately 10% of wealthier farmers in East Java have been able to purchase the hybrid Supadi variety. Improved varieties developed by the private sector should be subsidized, while ongoing public research and development continues. Local extension is currently overseen by the Regency government's Institute for Agricultural Dissemination (BPP), input suppliers are also a natural conduit for both the dissemination of agricultural inputs and cultural know-how. BPP, supplied with additional resources to accomplish the task, is well-positioned to up-skill them to fully-qualified extension agents that are able to spread information about improved practices, biofertilizers, and the correct application of biopesticides. Local farmer institutions, such as the Pest Control Farmer's Movement (GERDA), also play an important role in disseminating training and should be engaged. While a digital platform for PA can enable extension agents to work with individual farmers on their own terms, climatic information and advisory services are critical to helping producers mitigate the impacts of environmental hazards. While such services are already provided by BMKG, farmers must physically visit the local office to access them, and the reports are viewed as inaccurate and often disregarded by farmers. A digital application that predicts and guides a proactive response to extreme climatic events would be beneficial to local stakeholders.

The gains of these improved inputs and cultural practices should be magnified by increasing local processing capacity. In particular, the provision of fast-drying ovens will mitigate moisture issues stemming from heavy rainfall and flooding, while enabling local producers and processors to increase profit margins [206]. Vertical dryers cost approximately IDR 500 million (US $35,500) and can dry 500 tonnes of rice at once. These can be employed at farmer group level but, despite ongoing MoA subsidization, have not been widely adopted in East Java. Horizontal dryers cost approximately IDR 50 million (US $3,550), can dry between 500 and 1,000 kg at once, and are more suitable for utilization at the individual farm level. Again, high costs have significantly limited adoption. The provision or subsidization of rice milling units would also enable local value capture at the processing stage of the value chain.

Finally, farmers from all the communities involved in this research view the expansion of existing fertilizer subsidies, through increased quotas and improved distribution mechanisms, as critical to enhancing their ability to cope with hazards. While subsidized inputs can be initially difficult to access due to a burdensome registration process, nearly all local rice farmers purchase subsidized urea, Ponshka, ZA, and Petroganik. Chemical fertilizers tend to be more popular as they are less voluminous, easier to transport, and achieve similar results to organic fertilizers with significantly smaller quantities. The sale of subsidized fertilizers is also an important revenue stream for input suppliers. Though sales margins are slimmer than those of full price alternatives, subsidized fertilizers are guaranteed to sell and most suppliers see a low-margin, high-volume sales pattern as preferential to a high-margin, low-volume one.

Fertilizers are subsidized between 75-81% and account for roughly 10% of rice production costs in Indonesia. Were the subsidy to be revoked in favour of longer-term investments into agricultural productivity, smaller, poorer farmers would require new forms of financial assistance as their margins would immediately come under additional pressure [19]. A shift away from input subsidies and toward direct payments to farmers has proven successful in the European Union Common Agricultural Policy's 1992, 2003, and 2015 reform measures [207]. This decoupling of support from specific inputs removes the incentive to apply chemical stimulants to crops, while income support provides farmers with greater leeway to spend as they see fit. Both contribute to livelihood development and, when payments are made partially contingent on the adoption of sustainable environmental practices, the sustainable management of natural resources. This shift will also be made easier by the implementation of SRI and PA techniques, which will reduce producers' dependence on chemical inputs.

Value Chain of Rice in East Java

RICE EAST JAVA	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	**Drought** - Positive Impact **Flood** - Positive Impact **Heavy Rainfall** - Positive Impact **Pest and Disease** - Positive Impact	**Drought:** >50% Income Loss **Flood:** >50% Income Loss **Pest and Disease:** >50% Income Loss **Heavy Rainfall:** 30% >50% Income Loss **High Temperatures:** 10% 30% Income Loss	**Drought:** 30% >50% Income Loss **Flood:** 30% >50% Income Loss **Heavy Rainfall:** 10% 30% Income Loss **Pest and Disease:** 10% 30% Income Loss	**Drought:** 10% 30% Income Loss **Flood:** 10% 30% Income Loss **Heavy Rainfall:** 10% 30% Income Loss **Pest and Disease:** 10% 30% Income Loss
Coping Mechanisms & Enabling Interventions	Encourage youth employment and mechanical innovation Introduce innovative tools and practices to increase yields at production stage Reform the fertilizer subsidy by increasing the quota and improving timeliness of supply, which would allow producers to purchase additional supplies from input providers Improve communication between actors along the value chain Optimize the performance of farmer institutions by actively ensuring all stakeholders are engaged	System of Rice Intensification (SRI) coupled with "Jajar Legowo" cropping system (planting rice paddy in rows with empty rows to allow wide spacing for crop management) Grow improved rice varieties Application of precise dosage of fertilizer to meet crop nutrient needs Promote use of biopesticides and natural predators for pests and diseases control Reform the fertilizer subsidy by increasing the quota and improving timeliness of supply Enhance the capacity of input sellers to act as extension agents Introduce regulations to protect from price shocks Increase access to credit and grants to invest in business development initiatives Improve access to inputs (especially labour)	Increase access to credit and grants to invest in business development initiatives Improve market information, especially concerning customer preferences Fast-drying ovens to speed up the drying process Use of rice quality sensors	Reform the fertilizer subsidy by increasing the quota and improving timeliness of supply Improve market information and regulations to protect from price shocks Increase provision of productive capital Introduce improved seed varieties and agricultural technologies Improve rice yields at production stage
Barriers (Combined)	Producers lack knowledge and capital for mechanical innovation Lack of young, skilled actors in the agricultural sector Public policies are not conducive to agricultural growth Lack of extension workers at the input supply stage Farmer institutions are not operating at sufficient capacity	Agriculture is seen by youth as a low-profit sector Lack of productive capital Public policies are not conducive to sustainable agricultural growth Farmer institutions are not operating at sufficient capacity Lack of skills on sustainable practices e.g. SRI Chemical pesticides viewed as more effective, cheaper and readily available than biological alternatives	Lack of productive resources including labour and land Human resources are scarce and expensive Difficulty researching improved grain varieties Lack of extension workers at the input supply stage limits the quality of production Farmer institutions are not operating at sufficient capacity	Lack of assistive agricultural policies Lack of extension workers at the input supply stage limits the quality of production Public policies are not conducive to agricultural growth Lack of extension workers at the input supply stage Farmer institutions are not operating at sufficient capacity Lack of extension services

**Losses indicate the percent of normal earnings lost due to individual environmental hazards, and are estimates provided by actors at each respective stage of the value chain. While some losses (in production rather than income) may influence further losses downstream, others may not, due to supply and demand-driven price fluctuations, complex supply chains, and the ability of certain value chain actors to diversify their livelihood sources, among other reasons.*

2. Transition toward high-value vegetable production in East Java

Improved cultural practices, strengthened information and advisory services, and enhanced access to agricultural credit would strengthen vegetable-related market systems, which are critical to local income generation, nutritional provision, and national food security.

Vegetable crops provide ample benefits for local communities and the national populace in the form of income generation, job creation, improved nutritional outcomes, and industrial development [208]. In East Java, improved on-farm practices have the potential to increase the quality and quantity of vegetable production. Improved seed varieties offer enhanced drought tolerance and can be pre-immunized to reduce the risk of pest and disease outbreaks. Biological inputs–biofertilizers, biopesticides, and biocontrol agents–are a feasible alternative to chemical inputs, offering similar benefits without the environmental damage. For example, a study in Central Java found that the use of biological fungicides effectively reduced fruit rot caused by anthracnose, and resulted in 18% higher yields than chemical fungicides [209]. Cattle manure is an important source of nitrogen for crop and soil nutrition, particularly when applied at the optimal time and quantity, and proper manure management techniques are also effective at reducing GHG emissions [210]. Farmers in East Java can increasingly utilize manure generated from the province's large cattle population for vegetable production in a low external input-sustainable system. Additionally, a pilot study in West Java yielded an average 4% reduction in GHG emissions from improved manure management practices through composting and on-farm application [211].

Similarly, the use of mulching and crop residues for moisture preservation and improved soil health should be promoted to ensure nutrients are cycled throughout and remain within the farming system. Terracing in sloped areas should also be promoted to reduce soil erosion and degradation. Rainwater harvesters, sprinkler and drip irrigation systems, and combining planting mounds with ditches are all simple ways of improving water availability and use efficiency, and complement all other practices. Advanced technologies such as tractors and trap lights for pest management are expensive, and should be subsidized in order to capitalize on the aforementioned practices.

Strengthened information and advisory services also play a key role in higher value vegetable production. Improved pricing information can help producers understand and predict seasonal price fluctuation and adapt cropping calendars accordingly, while climate advisory services will help mitigate the impacts of less predictable environmental hazards. Awareness of new and innovative technologies is generally low, and producers are keen to better understand what state-of-the-art technologies they may benefit from [208]. Proliga, used to multiply the production of chilis, is an example of a nationally-developed technology that producers would likely benefit from but know little about.

Several studies have demonstrated that SMEs able to access the government's agricultural credit (KUR) enjoy increased profitability, earn more revenue, and accumulate more business assets [169]. While these loans have become exceedingly popular, access is limited by administrative and bureaucratic hurdles. Producers still must physically visit a bank branch authorized to distribute funds, and while KUR loans do carry reduced collateral requirements, they are still out of the reach of many micro and small producers [212]. Streamlining fund distribution through a digital platform and lessening capital required are ways of making the KUR system more responsive to the needs of farmers, and in turn increasing the productive capital available for small producers to develop their businesses. Additionally, these loans carry risk for producers–especially those dealing with acute climatic hazards–and should be paired with insurance mechanisms to protect lenders from default (see *CSA Recommended Provincial Intervention Package 6*).

Smallholders require trained professionals who can explain loan terms in plain language, work closely with at-risk borrowers, and ensure that non-collateralized credit is used for its intended purpose [208].

To maximize the benefits for value chain actors, productivity gains at farm-level will need to be matched with enhanced local processing capacity and improved market access. The provision of chilled storage between 6-8° C and 80-90% humidity will extend the shelf life of vegetables and enable value chain actors to better weather price shocks [213]. However, large-scale chilled infrastructure at the village level is expensive, as is the electricity required to power it. Chilled warehouses are required to take full advantage of the chilled transportation networks that are readily available, and able to increase marketing opportunities by allowing sellers to connect with buyers of greater geographical dispersion, and national-scale retailers. Finally, business training is both desired and needed for individual actors and cooperatives to maximize on all these gains in productivity and marketing. Specifically, training related to product marketing, demand planning, and value chain integration are desired in East Java.

Pricing information is also key in guiding producers' commercial and marketing strategies. Procedures for sharing this information should be kept as simple as possible, with the current prices being paid for basic and premium vegetable varieties communicated via regular farmer meetings [208]. With additional resources this initiative also be scaled into a digital application to offer visibility of regional pricing variations across the country, although additional work would be required to ensure adoption.

Value Chain of Vegetables in East Java

VEGETABLES EAST JAVA	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	**Drought:** >50% Income loss **Flood:** >50% Income loss **Heavy Rainfall:** >50% Income loss **Pest and Disease:** >50% Income loss	**Drought:** >50% Income loss **Pest and Disease:** >50% Income loss **Heavy Rainfall:** <50% Income loss **High Temperatures:** <30% Income loss	**Pest and Disease:** <30% Income loss	**Drought:** <50% Income loss **Heavy Rainfall:** <50% Income loss **Pest and Disease:** <50% Income loss
Coping Mechanisms & Enabling Interventions	Plant unsold seeds to diversify income streams Focus more on selling subsidized supplies, which are guaranteed to sell Discount slow-selling seed varieties to shift backstock Improve the quantity and skill of workers Expand market access / connect with more buyers	Build and install water collector, drip irrigation or sprinkler systems to improve water availability and -use efficiency Connect farmers with a wider array of buyers Improve the speed and certainty of subsidized fertilizer distribution and climate information services Employ improved inputs, like improved varieties, pre-immunized seeds, organic fertilizers, biofertilizers and biocontrol products Use improved crop rotations/cropping calendar Terracing and building ditches on sloping land to reduce erosion and increase soil-water catchment capacity Mulching and utilization of crop residues for soil moisture preservation	Store collected goods for longer to wait out drops in price Improve awareness of technological innovations Improve information related to marketing opportunities Recruit more female workers in the sector	Train producers to use solar-powered and ultraviolet lamps to increase garlic productivity Ensure the steady production of export-quality goods, so that marketers can sell to international customers Increase access to a wider variety of buyers Fix prices to prevent financial losses
Barriers (Combined)	Farmers lack capital to purchase goods Delayed information Poor market accessibility/transportation is often disrupted	Water often too scarce to water crops daily + can't afford to purchase water collectors. Water collectors rely on rainfall, so are not effective during drought. Can't afford high quality inputs (tools, labour, immunized seeds, organic fertilizer, diesel) Lack of awareness concerning crop rotations, seasonal conditions, and new technologies Lack of pricing information + high fluctuations in price Poor labour availability + can't afford labour-reducing technologies Chemical pesticides are cheaper and faster-acting that biological pest and disease controls	Lack of funds to build/buy warehousing facilities Demand often exceeds supply Lack of productive capital Labour shortages decrease the quality of production	If the RDKK (Definitive Plan for Farmer Group Needs) is not accurate or if it is delayed, farmers aren't able to access subsidized fertilizers and supplies decrease Difficult to engage buyers that aren't local Price fluctuations impact profit margins Government policies don't support high quality production Labour shortages decrease the quality of production

3. Promoting district-level sustainable oil palm production and integration with cattle and small ruminants in North Sumatra

Growing revenues on existing oil palm farms, rather than expanding production into new areas, will be key to safeguarding the economic windfall oil palm generates for the Indonesian economy while preventing further deforestation and peatland degradation. Several approaches to sustainable palm oil production are worthy of deeper examination. Additionally, *by integrating oil palm and cattle or small ruminant production systems, the two can provide mutual benefits for each other in the form of inputs and productivity, all the while increasing net incomes and reducing labour requirements.*

A recent World Bank report notes that "although oil palm plantations are not the primary driver of deforestation, they are the last and most profitable phase of a land governance system that incentivizes the degradation and eventual conversion of natural forests" [110]. Given oil palm's profitability and increasing suitability in Indonesia, production is likely to increase over coming decades. Ensuring that gains come from sustainable intensification as opposed to expanded areas of cultivation will be key to protecting primary forests, peat lands, smallholder livelihoods, and sectoral growth.

This means that improved on-farm practices should be matched with increased funding for small and medium-sized producers, as well as the villages and districts where future deforestation is most likely [134]. Specifically, a performance system that incorporates Indonesia's various legal frameworks and empowers district governments to engage in jurisdictional sustainability certifications should be scoped and piloted, with the aim of both preventing further environmental degradation and increasing the economic incentives, at farm-level, to intensify rather than expand oil palm production [134].

Additionally, the integration of cattle and small ruminants into oil palm farming systems provides myriad benefits for producers. By grazing animals in oil palm fields and utilizing the resulting manure as a natural fertilizer, soil fertility improves and yields of fresh fruit bunches have been shown to increase by up to 17% [214]. The commercial producer New Britain Palm Oil has reported a 39% increase in profitability per hectare by switching to a half stand system, in which oil palm density is reduced to 50%, and introducing cattle for beef production [215]. While revenue from beef production grew net incomes, the fertilization benefits from cattle grazing also contributed to oil palm productivity, which reached 68% the yields of a full oil palm stand at 50% density [215]. In Malaysia, livestock-oil palm integration helped drive a 14% increase in yields of fresh fruit bunches on small farms averaging 2.5 ha in land area [216]. In Bali, the introduction of livestock improved yields of fresh fruit bunches by more than 10% in semi-intensive systems, and by more than 30% in extensive systems, while reducing fertilizer and weeding costs in both [217].

Cattle also act as "natural lawnmowers," particularly when oil palm is intercropped with climate-smart forage grasses and legumes for grazing. Several forage species well adapted to oil palm plantations have been trialed in different areas including *Brachiaria* sp. (Ruzi, Brami), *Stenotaphrum secundatum*, *Paspalum conjugatum*, *Arachis* sp., *Vigna* sp., *Clitoria ternatea*, and *Stylosanthes guianensis* [218,219]. The introduction of cattle to oil palm production systems also reduces chemical herbicide use as the animals perform biological weed control, while maintaining understory vegetation at a height that is tall enough to protect the soil, but low enough for harvesters to access the oil palms [220]. This has the knock-on effect of increasing labour availability by 25-50%, reducing input costs by mitigating the need for herbicides, reducing the cost of weeding by 16-40%, boosting biodiversity by protecting dung beetles, conserving soil fertility, and mitigating GHG emissions by reducing the overall amount of chemical inputs in the system [214,221,222,223]. Farmers should be trained on these benefits, which can be further amplified by promoting the use of organic fertilizers and biopesticides over their chemical counterparts.

Improved on-farm practices and conservation agriculture techniques such as cover crops, terracing, contour farming, mulching, and intercropping arabica with legume trees will also improve crop performance on sloping land, protect soil from rainfall, and reduce erosion. Conservation agriculture (CA) also has the potential to mitigate carbon emissions through soil organic carbon (SOC) sequestration. A meta-analysis of CA in the Tropics showed annual increases in SOC stock under CA practices (0.16 – 0.96 Mg C ha^{-1} yr^{-1}) as compared to conventional practices [224]. Improved sorting capacity at the production stage to separate ripe and unripe fresh fruit bunches would potentially allow them to sell their harvests at a higher price and reduce labour requirements at the processing stage. The provision of tarpaulins would help reduce post-harvest losses as they are more effective at minimizing the quantity of fresh fruit bunches lost during transportation than the nets that are currently being used.

Two existing government programmes, the System of Integration Cattle–Oil Palm Plantations (SISKA) and the Integrated Oil Palm - Sheep Production System, both administered by IAARD, are potential vehicles for promoting this hybrid farming system. Originally established to facilitate connections between cattle breeders and smallholder oil palm producers, SISKA's role can be expanded to provide subsidies and credit to help small farmers purchase cattle (which currently takes place through the KUR agricultural credit system), provide other inputs such as certified oil palm seedlings and biological applications, administer veterinary and vaccination services, and help small and medium-sized producers access the KUR agricultural credit. While SISKA is currently operating in some North Sumatran districts, additional funding would enable an expansion of its geographical reach. North Sumatra also maintains a research institution for small ruminants which can be engaged to provide local knowledge on small-ruminant-oil palm integration.

Finally, diversified income streams should be developed to help oil palm producers become more resilient to environmental hazards and develop lower-emission livelihood sources. Interventions should primarily target the development of market systems surrounding cattle meat and dairy products. National demand for beef consistently outstrips supply and is forecasted to increase steadily over coming years [69]. While North Sumatra is not currently a major beef producing hub, increasing the province's production and processing capacity is an economically feasible strategy that should be able to attract both seed investment and buyers.

Value chain of Oil Palm in East Java

OIL PALM NORTH SUMATRA	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	**Drought:** <30% Income loss **Flood:** <30% Income loss **Pest and Disease:** <30% Income loss **Heavy Rain:** <30% Income loss	**Drought:** <10% Income loss **Heavy Rain:** <10% Income loss **Pest:** <10% Income loss	**Heavy Rain:** <10% Income loss	**Heavy Rain:** <10% Income loss
Coping Mechanisms & Enabling Interventions	Provide extension services to farmers related to the use of fertilizers, pesticides, and stimulants Motivate field officers from local savings cooperatives to be more active in visiting members' homes to offer credit packages, explain loan terms, and collect monthly repayments, which would increase demand for inputs Training in GAP stages 1 & 3 (knowledge and information) to help farmers properly cultivate fruit bunches and allow them to fully ripen Lack of certified seeds/seedlings to sell to farmers Expand government programmes to provide certified seeds and cattle	Training in GAP stages 1 & 3 (knowledge and information) to help farmers properly cultivate fruit bunches and allow them to fully ripen Integration of cattle and goats in oil palm field for improved soil fertility (manure), weed control Conservation techniques on sloping land e.g. cover crops (nuts, elephant grass), terracing, contour farming, mulching Introduce government price regulations to protect from financial losses Promote use of organic fertilizers and biopesticides to reduce overreliance on chemical inputs Replanting program with high quality, certified seeds/seedlings	Use a tarpaulin to protect fresh fruit bunches during transport Training in GAP stages 1 & 3 (knowledge and information) to help farmers properly cultivate the fresh fruit bunches, allow them to ripen uniformly, and harvest them Improved sorting of raw/unripe fruit at the production stage reducing costs at processing stage	Use a tarpaulin to protect fresh fruit bunches during transport Training in GAP stages 1 & 3 (knowledge and information) to help farmers properly cultivate the fresh fruit bunches, allow them to ripen uniformly, and harvest them Improved sorting of raw/unripe fruit at the production stage, improving quality and competitiveness on international markets
Barriers (Combined)	Field officers often visit when farmers aren't home	Poor labour availability Lack of information and access to improved seed varieties Some communities believe that cattle harm soil fertility Prohibitively high costs restrict transportation and terrace building	Poor labour availability Limited access to government program / KUR credit for farmers leads to poor quality production Sorting out unripe fruit requires significant time and labour Farmers lack the capital to produce high quality fruit	Poor labour availability Limited access to government program / KUR credit for farmers leads to poor quality production Sorting out unripe fruit requires significant time and labour Farmers lack the capital to produce high quality fruit

4. Strengthen the value chain of Arabica Coffee in North Sumatra

While arabica coffee is hugely important to the North Sumatran economy, it is a climate-sensitive species that will require adaptive cultural practices and comprehensive value chain interventions to persevere

Improved inputs for arabica coffee are key to reaping greater value at downstream value chain stages. The provision of improved local varieties, such as coffee gayo, that are drought tolerant, pest and disease-resistant, high yielding, and certified, will create higher value returns at downstream value chain stages. Input suppliers should also be supported in diversifying their portfolio of goods and services, particularly with regard to biofertilizers and biopesticides. In addition to reducing farmers' reliance on chemical inputs, organic fertilizers have been shown to improve coffee quality and, in the case of biofungicide powder (*Beauveria bassiana*), curtail Coffee Berry Borer populations by up to 25% [225]. Shade trees can be used to mimic arabica's original forest environment and protect the sensitive plants from extreme temperatures and high-intensity sunlight [226,227]. Seedlings for shade trees are both in-demand and will increase yields of producers' primary cash crop. In Indonesia, arabica coffee intercrops particularly well with legume trees such as dadap (*Erythrina sububrams*), gamal (*Gliricidia sepium*), and dan lamtoro (*Leucaena glauca*), which are also useful for livestock feed and improving soil fertility [227]. Shaded coffee systems can also lower net GHG emissions (-1.5 Mg CO2e ha-1) due to increased carbon stock, as compared to unshaded systems (2.8 Mg CO2e ha-1) [228]. Shaded intercropping can also result in diameter growth increases of up to 8% in the first year and 13% increased cherry growth, as well as general improvements in dry bean weight, seed growth, leaf growth, and height [227].

At the production stage, training on good agricultural practices improved practices from nursery to harvest can increase profit margins. Pruning, integrated pest management (IPM), and improved fertilization procedures are just a few practices that producers desire training for. The increased use of shade trees will reduce water consumption and reduce pests and weeds. Several production crops, such as avocado, cashew, and macadamia, intercrop well with arabica coffee in North Sumatra, and can function as stand-alone livelihood streams for producers. The provision of BROCAP coffee berry borer traps, which are effective but expensive, would also help limit pest-induced losses. The application of lime, dolomite, and other organic soil amendments will reduce soil acidity. Finally, moisture monitoring equipment should be used to limit the moisture content of coffee to below 12% in order to reap maximum value at market.

Developing local processing capacity, particularly through the use of dry houses and drying machines, would increase saleable yields and reduce post-harvest losses. Sorting machines would also reduce labour requirements by automating a process that is arduously manual. Similarly, coffee grading and quality certification procedures will increase the value of harvests and enable transactions with a larger number of higher-paying buyers at the marketing stage.

While recent research has demonstrated that geographical indications and place-based marketing strategies have not been successful in adding value to the Indonesian coffee sector, facilitating connections between local producer groups and lead firms will likely prove more lucrative [229,230]. Participation in global coffee fairs and competitions can help connect local producers with wholesalers and large customers in the hotel, restaurant, catering, and cafe sectors. Finally, the market systems for new fruit and nut varieties employed as shade trees should be developed. Avocado, cashew, and macadamia are all profitable production systems in their own right and local processing facilities and marketing opportunities, both near and far, will help maximize local value capture.

Value Chain of Arabica Coffee in North Sumatra

COFFEE NORTH SUMATRA	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	**Drought:** <50% Income loss **Heavy Rain:** <30% Income loss	**Pest and Disease:** <30% Income loss **Drought:** <10% Income loss	**Pest:** >50% Income loss **Heavy Rain:** <30% Income loss **Drought:** <10% Income loss **Heavy Rain:** <10% Income loss	**Heavy Rain:** <30% Income loss **Pest and Disease:** <10% Income loss
Coping Mechanisms & Enabling Interventions	Diversify portfolio of products and services	GAP training for arabica coffee production (cultivation methods, use of improved and adaptive varieties, integrated pest management, ISFM) Increase pruning, planting of cover crops, planting of annual crops, and replacement of crops with improved varieties (especially Coffee gayo) Plant shade trees, use brocaps (traps), and utilize natural pesticides made from tobacco, neem, garlic to protect coffee plants from pests Application of soil amendments such as lime, manure; promote use of biofertilizers and biopesticides Planting shade trees, which act as a weed control measure and profitable in their own right (avocado, macadamia, cashew) Chase monkeys away from plants to reduce losses	Advise farmers not to harvest when it rains Use tents, moisture monitors, and drying warehouses to protect harvests from rain Continuously innovate new products to keep customers interested Apply for credit programmes administered by the local office of the Ministry of MSMEs and Cooperatives in order to purchase drying warehouses	Continuously innovate new products to keep customers interested Work with producers to institute coffee grading standards and quality certification Have producers and processors use tents, moisture monitors, and drying warehouses to reduce moisture levels Participate in coffee exhibitions and festivals to promote local coffee varieties and brands Assess the market potential of different arabica varieties and facilitate links between local producers and large wholesalers and retailers (like Starbucks)
Barriers (Combined)	Lack of capital to invest in business development	Poor labour availability Lack of information on improved varieties Decreased tobacco production makes it difficult to produce natural pesticides from tobacco leaves Easy and cheaper to user chemical pesticides as opposed to natural ones Lack of access to finance Brocap pest traps are prohibitively expensive Lack of capital to purchase and plant shade trees	Farmers require quick returns on their crops, so harvest when it rains even though this makes the coffee more difficult to process Insufficient labour resources limit the extent to which tents and tarpaulins can be used to protect harvests from heavy rain Lack of capital to purchase dry houses Cost of vehicle transportation (esp. fuel) limits how often harvest can be sold	Drying houses are prohibitively expensive

5. Facilitate diversification in maize production systems to incorporate more drought-tolerant commodities in Nusa Tenggara Timur

As actors at all stages of the value chain have articulated the great difficulties surrounding maize production in increasingly arid NTT, drought resistant alternatives will be key to future-proofing local agricultural livelihoods and food security.

As maize suitability decreases and NTT's population increases, local production systems will increasingly rely on a diverse variety of hardy, nutritious, and economically-viable alternatives [231]. With climate change projected to severely impact maize suitability and yields in NTT by 2050, locally-focused research and development initiatives, in conjunction with extension and advisory services. are the best means of quickly identifying suitable alternatives and up-skilling producers on their cultivation (see *Economic Impacts of Climate Change*). While sorghum, mung bean, and peanut are already intercropped with maize in the region, pumpkin, cucumber, and other legume crops such as rice bean and green bean, may also be potential substitutes with additional benefit of enhancing soil fertility. Upland paddy rice, cassava, soybean and sweet potato are also cultivable throughout NTT by adjusting cropping patterns to suit local rainfall, temperatures, and humidity [232]. In addition to livelihood generation, new cropping systems will need to fill the dietary gap left by decreasing maize production, as catemak corn (maize mixed with pulses) is a staple food in many provincial districts [233].

Thus, dedicated scientific research is required to confirm which are most suitable from both an agroecological and economic perspective. However, sorghum, which is dry climate adapted, does not require chemical inputs, grows well in marginal areas, and is nutritious as maize, presents particular benefits for local food security as a staple crop, and economic growth as a raw material for industrial use [234]. Diversification should also include locally adapted livestock species. Small ruminants are generally less dependent on rainfall and offer diverse opportunities for livelihood generation, as well as resource cycling through manure application [235].

Once research has confirmed viable future-oriented production systems, the development of locally-suited varieties and cultural practices must be developed and then disseminated through extension services. While new practices and technologies will likely need to be developed, many existing practices are already being employed at low levels in the province to address endemic risks, and will need to be scaled up. These include: conservation agriculture through the use of reduced tillage, mixed and relay cropping (especially with legumes to provide nitrogen fixing benefits), alley cropping, and contour farming to reduce soil erosion; integrated pest management (IPM); an adjusted cropping calendar–informed by reliable climatological forecasts–to facilitate year-round harvests; early land preparation to pre-empt early onset rains [236].

Contemporary agricultural techniques should be combined with indigenous knowledge and traditional cultural practices such as the use of embung water reservoirs, the mamar production system, to distribute and preserve scarce natural water resources, and the kaliwu production system, for land management [232]. Extension workers themselves require additional training in contemporary and traditional practices, and an early warning system should also be implemented to forecast and notify producers of impending climate hazards, potentially in partnership with Indonesia's Meteorological, Climatological, and Geophysical Agency (BMKG).

While the long-term goal should be to diversify production and reduce communities' reliance on maize, the mainstay cash crop will play a critical role in livelihood generation for the foreseeable future. Thus, the development and dissemination of drought-tolerant, short-duration, high-yielding maize varieties, such as Lamuru, hybrid, and local varieties (five leaf maize and seven leaf maize), should also be prioritized. While local varieties yield less than 2 tonnes/ha, open pollinated varieties (including Lamuru) yield closer to 9 tonnes/ha, and hybrid varieties as much as 13 tonnes/ha. Currently, a small number of farmers are producing five and seven leaf maize, which can reach maturity in just 26 says and is well-suited for the production of livestock feed. Improved hybrid varieties are cultivated locally for human consumption, though their use is not widespread and should be encouraged. To achieve this, seed availability must be improved. A greater challenge will be helping producers source the increased inputs (fertilizer, water, labour) these higher-yielding varieties require.

Processing infrastructure and marketing opportunities for new production systems must also be developed to ensure maximum local value capture. A key barrier holding back producers from switching to improved hybrid maize varieties is a lack of marketing opportunities. This shift can be accelerated through the formation of cooperatives, subsidies for processing equipment, and the formation of public-private partnerships. Economic ecosystems will also need to be developed for sorghum, mung bean, peanut, and the vegetable crops maize will be intercropped with. Additionally, processing capacity and marketing opportunities for the conversion maize to livestock feed should be further developed.
As it is, pig production in NTT is heavily dependent on maize-based feed that is locally produced, but there is room for greater scale.

Finally, women currently lack equal access to educational opportunities, financial capital, and influence in household and farmer group decision-making processes in NTT's maize production system. Gender issues should be mainstreamed into the curriculum of agricultural extension services and technical guidance (Bimtek) programmes with the goal of dismantling the barriers that restrict and undervalue women's participation in agricultural production systems. Training on good agricultural practices, the use of advanced machinery, innovative technologies, business development, and how to access and manage financial capital would help close the gap between male and female stakeholders.

Value Chain of Maize in Nusa Tenggara Timur

MAIZE NUSA TENGGARA TIMUR	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	Drought: >50% Income loss Pest: <30% Income loss High Temperature: <30% Income loss	Drought: >50% Income loss High Temperature: <50% Income loss Pest: <30% Income loss	Drought: >50% Income loss	Heavy Rain: >50% Income loss Pest: <50% Income loss
Coping Mechanisms & Enabling Interventions	When maize crops fail and producers no longer require inputs, switch to selling inputs for vegetable production Promote Integrated Pest Management (IPM) to supply appropriate pest control inputs	Intercrop or substitute maize with early-maturing, drought-tolerant crops such as vegetables, sorghum, legumes, and rice bean Remove stunted crops before harvest time and use for livestock feed, freeing up space to plant green beans and sweet potatoes as a replacement crop Promote conservation agriculture (reduced tillage, mixed/relay cropping) and contour farming Early land preparation and adjusted cropping calendar to anticipate rains Use of drought tolerant, short-duration, high-yielding maize varieties (lamuru, hybrid, and local varieties) Integrated Pest Management (IPM) - pest tolerant varieties, appropriate pesticides application and planting trap crops around maize plants	When maize isn't available, pivot to producing alternative commodities with the available raw materials, like sweet potato chips, fried peanuts, (egg peanuts / peanut onions), or fried shallots Store corn on palettes and use tighter plastic wrap to prevent moisture penetration	When heavy rains increase the moisture content in corn, re-dry it or sell at a lower price Promote fumigation and sorting of corn at production stage to reduce damage, decrease losses, and maintain quality
Barriers (Combined)	Lack of information for producers on new planting materials for vegetable production so input suppliers can then supply them with the related inputs	Farmers lack information on which crops are well-suited to local drought conditions Farmers lack training in vegetable production and are intimidated by the number of competitors in the market Lack of climate information (weather forecasts) Farmers still prefer to use local maize varieties Limited knowledge on IPM and overreliance on chemical pesticides	Drought results in decreased supply, forcing processors to pay higher prices	Warehouses to store and dry corn are expensive Marketers lack productive capital to invest in facilities Poor labour availability at farmer level results in un-sorted maize, which harms marketers

6. Value chain interventions to improve the quality of pig production in Nusa Tenggara Timur

Pig production can be increased through the provision of higher quality inputs, such as boar semen and the means to transport it, and by upgrading housing pens to prevent disease spread. Increased financial investment in the form of credit schemes and agricultural insurance mechanisms will then be required to capitalize on these productive gains.

Improved input provision is key to injecting additional value into NTT's pig value chain. At base level, a boar breeding programme is required to ensure an adequate supply of high-quality semen. Artificial insemination is key to increasing reproductive efficiency as it reduces the costs and time related to natural mating, guarantees the genetic transmission of superior quality stud, and reduces disease transmission [237]. Labour resources are insufficient to meet current demand for inseminators and, as this is a male-dominated field, programmes to incentivise and subsidize female employment should be promoted. Additional equipment, particularly blowers are also needed in order to scale-up operating capacities, and liquid nitrogen required for transporting semen is expensive and difficult to source. A steady supply of semen from improved boar varieties and high yielding individuals is also important**.** As African swine fever remains a critical issue in the province there is also an opportunity to train input suppliers in basic veterinary practices that may help prevent its spread, including the administration of government-supplied vaccinations that will hopefully be ready for distribution by the end of 2021.

At the production stage, pig rearing practices resulting in decreased input requirements and higher yields should be prioritised. Litter size, birth weight, number of piglets weaned, adult size, meat yield, and mortality rates all suffer simply because producers lack the capital to feed their pigs [237]. Fodder is expensive and still largely imported, while water is perennially scarce [238]. Additional water resources are also required through the increased use of rainwater harvesters and small-scale irrigation systems, and pig pens should also be upgraded and maintained in order to reduce pest and disease spread. Regular disinfecting, improved sanitation measures to transport and store feces in septic tanks, the installation of barriers to prevent flooding, and the vertical expansion of pens to improve air circulation are all practical and affordable improvements that can be made. For approximately IDR 5 million (US $350), an existing pen can be upgraded with a septic tank, raised ceilings, rainwater collector or underground water pump, and a cleaning kit.

Though credit schemes are available, repayment periods should be extended to at least four months, allowing producers to earn returns before repayment comes due [238].. Local pig producers can be connected directly with local maize producers to capitalize on low quality corn production that would otherwise be wasted (see *Recommended Provincial CSA Intervention Package 5),* while the development of local fodder factories should be developed to scale production to industrial levels [238].

Agricultural insurance schemes are also key to protecting pig value chain actors and encouraging investment. As pig rearing is capital-intensive, environmentally-induced losses have drastic impacts on the incomes of producers. Commercial finance institutions, well aware of the risks involved, will not create insurance products for pig producers. Thus, the public sector has an enabling role to play in the development of insurance schemes to de-risk producers [238]. The Government of Indonesia, through state-owned banks, currently operates insurance schemes for rice and cows and has implemented support schemes to assist cattle producers impacted by recent disease outbreaks. These programmes can serve as a model for new schemes to support actors along NTT's pig value chain.

Value Chain of Pig in Nusa Tenggara Timur

PIG NUSA TENGGARA TIMUR	INPUT SUPPLY	ON-FARM PRODUCTION/HARVESTING	COLLECTION/PROCESSING	MARKETING
Hazards + Impact Severity	**Pest and Disease:** >50% Income loss **Heavy Rainfall:** <50% Income loss **Flood:** <30% Income loss **Drought:** <10% Income loss	**Pest and Disease:** >50% Income loss **High Temperature:** <30% Income loss **Drought:** <10% Income loss	**Pest and Disease:** >50% Income loss	**Pest and Disease:** >50% Income loss
Coping Mechanisms & Enabling Interventions	Train input suppliers to manufacture and supply alternative pig feeds Secure access to higher quality semen from improved pig breeds Provide credit for business development (upgrade insemination equipment, water supplies, purchase additional male pigs purchased, and produce more semen) Improve marketing information or relocate business to a more strategic location, closer to a larger number of buyers	Use of improved breeds (Duroc, Landrace) and improved artificial insemination services Ensure full vaccination and routine medical treatment to prevent disease outbreaks Prevent pest and disease by ensuring feces is stored in a septic tank, and regularly disinfecting pens Use of high quality feed made from local materials Secure additional water supplies, which are often unavailable but needed Improve cage construction to prevent flooding and improve air circulation Mitigate hot temperatures by watering the pen and livestock to maintain stable temperature / keep humidity levels low by keeping the pens dry and reducing the height of the sack pile	Provide credit for household-scale businesses in order to fund business development efforts Provide additional training for technical personnel Develop livestock insurance products to protect producers–who are often also processors and marketers–from losses	Provide credit for household-scale businesses in order to fund business development efforts Develop business insurance products to protect actors from environmental hazards
Barriers (Combined)	Poor availability of skilled labour Lack of capital to invest in blower technology, insemination equipment, and advertising Geographic location of home/shop limits access to customers + lack of information on how to connect with customers outside of local area Extension information still provided mainly through social media (scarce and sometimes incorrect) Pig feed market is saturated/very competitive, driving down margins and revenue Liquid nitrogen (used for transporting semen) is prohibitively expensive	Lack of capital to purchase additional water resources Lack of collateral makes it difficult/impossible to secure business loans Limited information concerning disease prevention Lack of technical assistance from institutions and official agencies Decreasing price of livestock impacts revenue Lack of high quality boars	Lack of capital to purchase additional water resources Lack of supply due to African swine fever reducing production Market demand does not always match supply Lack of livestock insurance increases risk	Lack of supply due to African swine fever reducing production Lack of insurance products to protect from environmental hazards Poor availability of skilled labour Regulations meant to prevent the spread of African swine fever prevent selling to customers outside of the local area Weak technical assistance from agencies, especially related to biosecurity

National outlook

While Indonesia has made progress in improving food security and raising large swaths of its population out of poverty, recent gains are fragile and under threat from a changing climate. Environmental hazards, such as increasingly erratic rainfall and high temperatures, are leading to decreasing suitability for staple crops, a scarcity of water resources, and severe pest and disease outbreaks. Additionally, non-environmental hazards such as a shortage of labour resources, unstable commodity prices, and poor access to finance further constrain agricultural productivity. On the other hand, cash crops like oil palm are projected to see major increases in suitability, pointing to economic opportunities as well as environmental risks. Although the agricultural sector will increasingly generate a smaller share of

Indonesia's GDP, it will remain of critical importance for livelihood generation and food security for decades to come, and thus must be future-proofed.

While Indonesia has made progress in improving food security and raising large swaths of its population out of poverty, gains made over past decades are fragile and under threat from a changing climate. In addition to having the fourth largest population, Indonesia is among the world's largest emitters of carbon. Though Indonesia's NDC states that energy generation is expected to overtake land-use change and forestry as Indonesia's largest source of GHG emissions, LUCF is far-and-away the largest current source of emissions. As climate change-induced increases in oil palm suitability indicate a high probability for areas under production to increase, there is a critical need for policy frameworks and robust enforcement mechanisms to protect Indonesia's globally important peat lands and tropical rain forests from further agricultural degradation.

Overall, Indonesia's Nationally Determined Contribution is graded as highly insufficient and at risk of not being achieved [130]. In line with the recent success of Indonesia's REDD+ agreement with Norway, the international community should engage the Government of Indonesia with additional results-based payment schemes. It is critical that payments for environmental preservation be funneled directly to producers in exchange for switching away from oil palm and other high-emissions crops. Until the financial benefits of not producing these crops outweigh those of producing them, the world should not expect Indonesia to shy away from additional intensification and extensification.

Progress is being made on several fronts. A recent trend in annual GHG emission reductions is a promising achievement, and the issuance of the first payment from Indonesia's REDD+ agreement with Norway indicates the potential of results-based payment schemes. However, Indonesia's achievement of its NDC target is uncertain due to land and energy-based emissions, and balancing the long-term benefits of terrestrial carbon sequestration with the short-term incentives of increased agribusiness will be a key factor in the policy's success, or failure. Further, if the agreement as a whole becomes imperiled, the risk of unmitigated deforestation will increase. The international community should provide financial incentives for Indonesia to strengthen its NDC commitments and technical resources to support their achievement. In turn, this money needs to reach the villages and districts where deforestation is most likely, in the form of incentives to complement new legal prohibitions and deforestation-free zones [134]. Social forestry–often lauded as a means of protecting Indonesia's forests and empowering forest communities–is at risk of becoming a greenwashed form of state control. Means of ensuring that power is truly devolved to communities and that local stakeholders are fully able to exercise their new authority are required to ensure the practice delivers on its stated goals [150].

Though private investments into CSA initiatives are growing larger and increasing numbers of value chain actors are able to access credit through the KUR programme, financial capital is still hard to come by for most of Indonesia's small producers. Expanding the KUR and making it easier to access is an achievable first step. This, in combination with new state-backed credit mechanisms and insurance products, is the best means of connecting poor farmers with capital, insulating agricultural communities from climate and non-climate shocks, and de-risking the sector to a point that the private sector is encouraged to invest.

Connecting large-scale investment with hundreds, thousands, or millions of small producers is a task best suited for the state but, in a country as populous and spacious as Indonesia, decentralization has made national-local coordination more difficult. Administrative means of connecting international funding with national policies and local implementation must be developed to facilitate the deployment of large finance packages. Increased coordination and formal partnership mechanisms that bridge the gaps between MoA, MoEF, and Bappenas will be required.

Producers and other value chain actors must also be protected from environmental and non-environmental shocks. The public sector will need to subsidize/enable private sector investment, particularly by underwriting agricultural insurance mechanisms and other risk management instruments.

Perhaps the most daunting obstacle facing the agricultural sector is how to increase and develop its human resources. Little short of the sector's wholesale modernization–including new digital technologies, ramped up business training, and improved access to financial capital–will allow the sector to compete with services, manufacturing, and other high value employment opportunities available to Indonesia's youth in urban areas. A holistic, national-scale campaign of agricultural research and development, to identify new crop varieties, livestock breeds, agricultural practices, and cutting-edge technologies is required, alongside significantly ramped-up extension services to ensure full dissemination. Though the decentralization of extension services poses a hurdle, with a stronger central thrust, MoA's local agency offices could become recruitment centers for young extension workers, and laboratories for localised R&D initiatives. Funding for such an ambitious initiative should come from savings incurred by reforming the national fertilizer subsidy, which in 2015 cost US $2.1 billion–more than 11 times the amount spent on R&D and extension combined [128].

National policies and programmes targeting increased CSA uptake must be buttressed with ground-level research and interventions. At local-level, challenges facing agricultural stakeholders need to be identified and matched with promising practices and technologies, while public and private-sector investment needs to reach those who need it most–vulnerable actors in agricultural value chains.

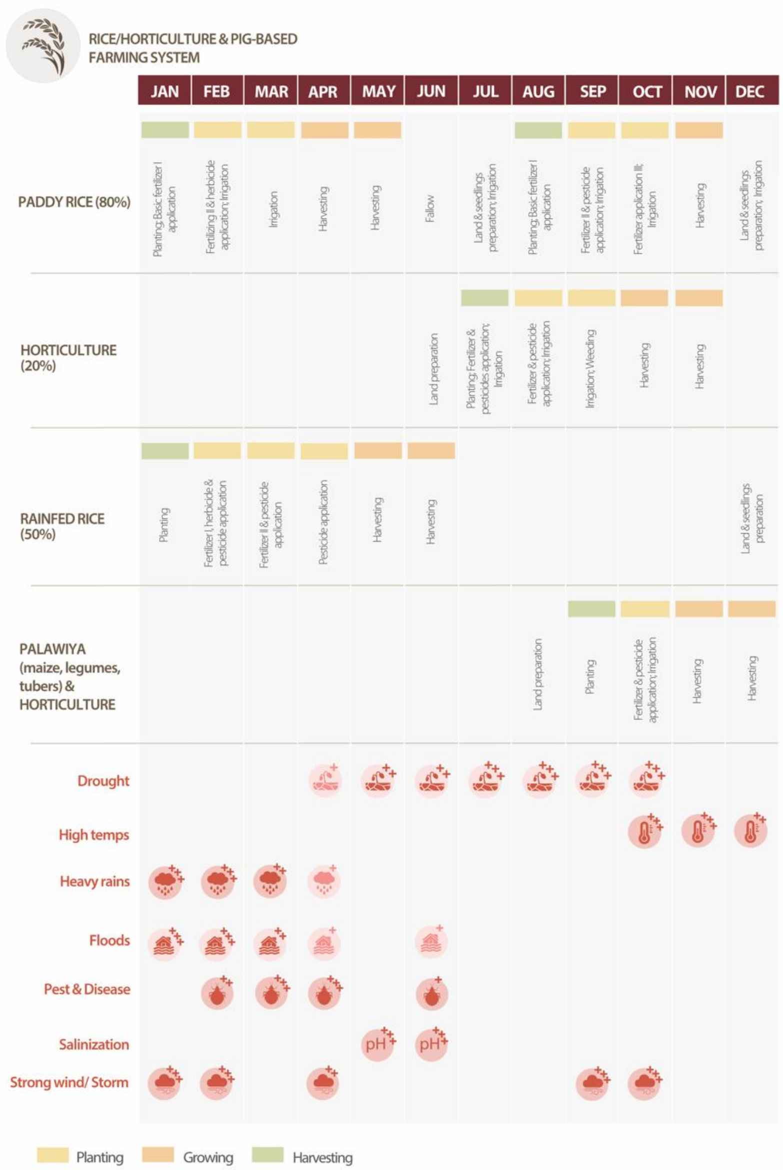
Next Steps

These CSA Intervention Packages are meant to serve as an evidence base for further analysis and, potentially, future investment. Typically, The Alliance of Bioversity and CIAT's Climate-Smart Agriculture Country and Provincial Profiles are followed by Climate-Smart Agriculture Investment Plans, which are based on the Climate-Smart Agricultural Investment Planning Framework.

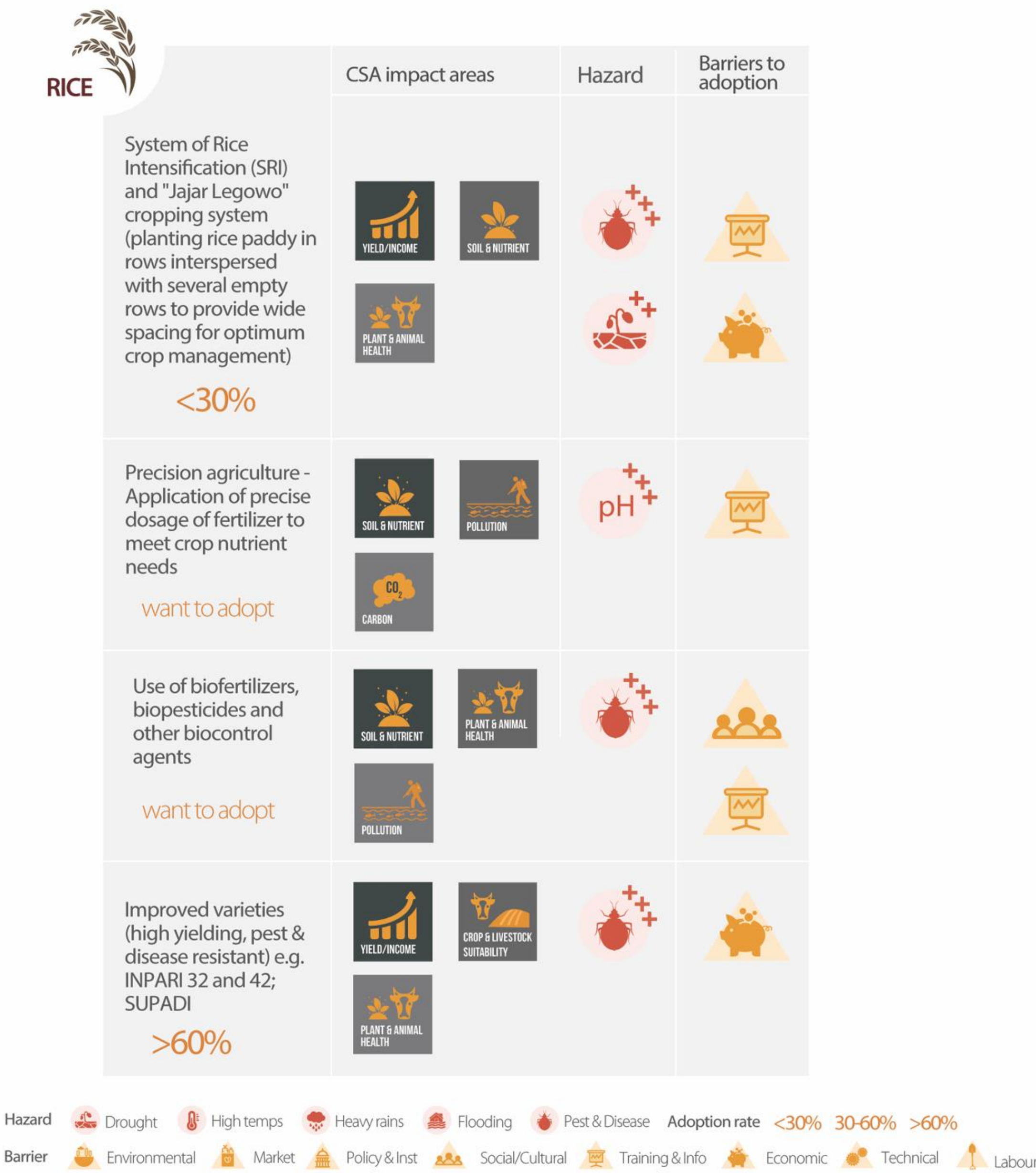
This Framework is based on the four components of CSA planning and implementation: (i) situation analysis, (ii) prioritizing interventions, (iii) program design, and (iv) M&E [239]. All four of these components depend on strong engagement with the key decision-makers, experts, and institutions involved. Each step serves as input to the others, moving from a careful analysis of the agricultural context, climate change projections and risks, and economic impacts, to the prioritization of CSA investments and program design–all embedded in a comprehensive theory of change and results framework. Importantly, the CSA Investment Plans would quantify the GHG mitigation and cost-benefit potential of each CSA intervention. CSA Investment Plans typically contribute to the implementation of NDCs, national development plans, and climate change adaptation strategies, as well as targets for the agricultural sector's growth.

Appendix 1: East Java

Cropping and hazard calendar for rice-based system



Prioritized on-farm CSA practices & technologies for rice



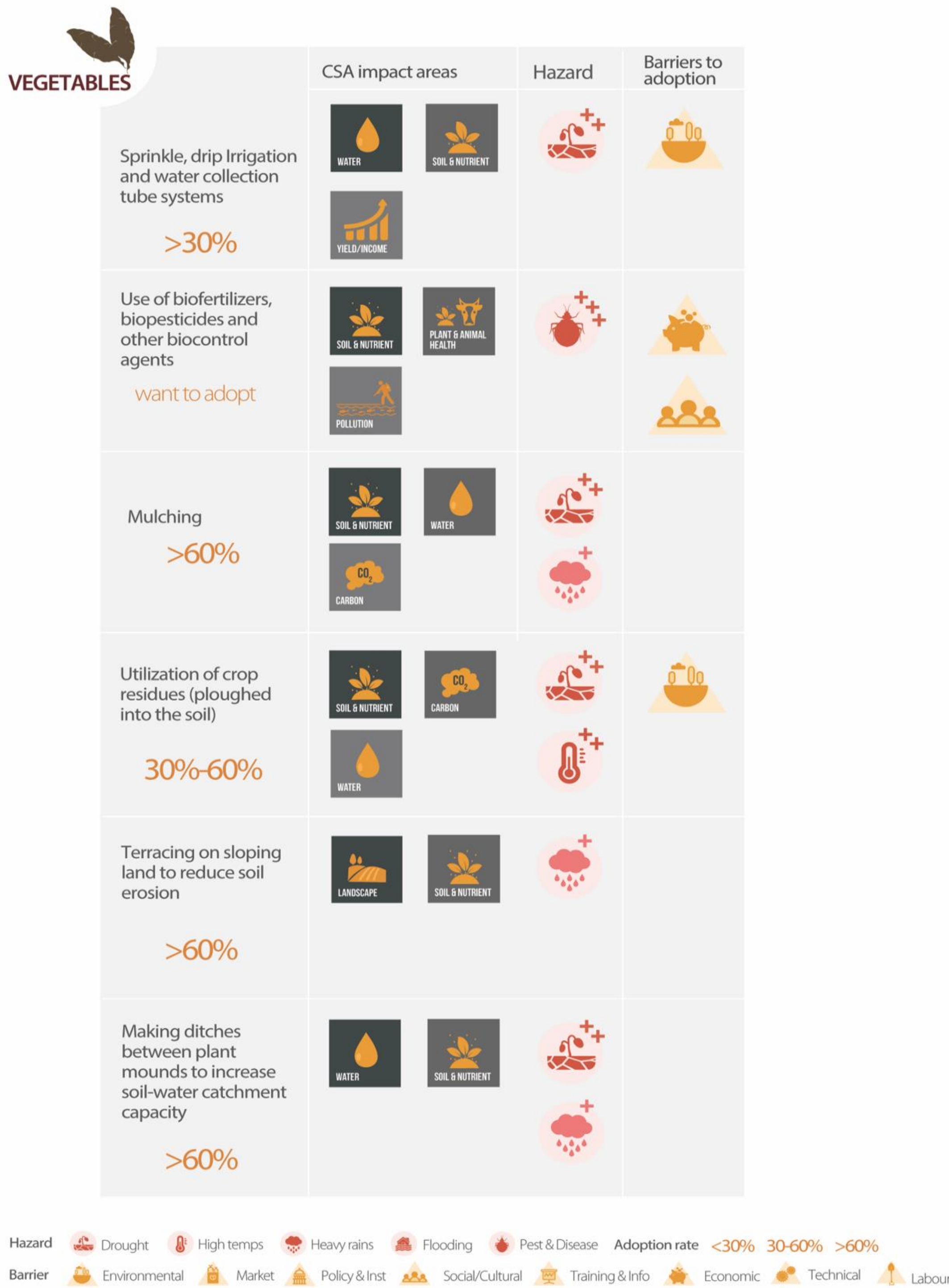
Cropping and hazard calendar for vegetable-based system

VEGETABLE-BASED FARMING SYSTEM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SHALLOT	Land preparation	Planting; Fertilizer & pesticides application	Pest management	Harvesting	Land preparation	Planting; Fertilizer & herbicides application	Irrigation; Pest management	Harvesting; seedlings preparation	Land preparation	Planting; Fertilizer & pesticides application	Pest management	Harvesting
TOMATO	Harvesting	Land & seedlings preparation; Herbicide application	Planting	Irrigation; Herbicides, pesticides & fertilizer application	Pest management; Irrigation	Fertilizer & pesticides application	Harvesting	Land & seedlings preparation	Planting	Irrigation; Herbicides, pesticides & fertilizer application	Pest management; Irrigation	Irrigation; Fertilizer & pesticides application
GARLIC					Land preparation	Planting; Fertilizer & herbicides application	Weed management; irrigation	Weed management; irrigation	Harvesting			
LETTUCE	Fertilizer application; Weeds & pests management	Harvesting	Land & seedlings preparation	Planting	Irrigation; Fertilizer & pesticides application	Harvesting	Land & seedlings preparation	Planting	Herbicides, pesticides & fertilizer application	Harvesting	Land & seedlings preparation	Planting
CABBAGE	Planting	Fertilizer & pesticides application	Pest management	Harvesting			Land preparation	Planting	Pesticide application; irrigation	Fertilizer & pesticides application	Harvesting	Land preparation
POTATO				Land preparation	Planting	Fertilizer & pesticides application	Weed & pests management; irrigation	Weed & pests management; irrigation	Harvesting			
POTATO	Weed management	Fertilizer & pesticides application	Weed management	Fertilizer & pesticides application	Harvesting	Top-up fertilizer application	Top-up fertilizer application	Harvesting II	Harvesting II	Land & seedlings preparation	Planting	Fertilizer & pesticides application
Drought								+	+	+++		
High temps		++	++									
Heavy rains	+	+										
Pest & Disease			+++	+++	+++		+++	+++	+++			
Strong winds										++		

Planting | Growing | Harvesting

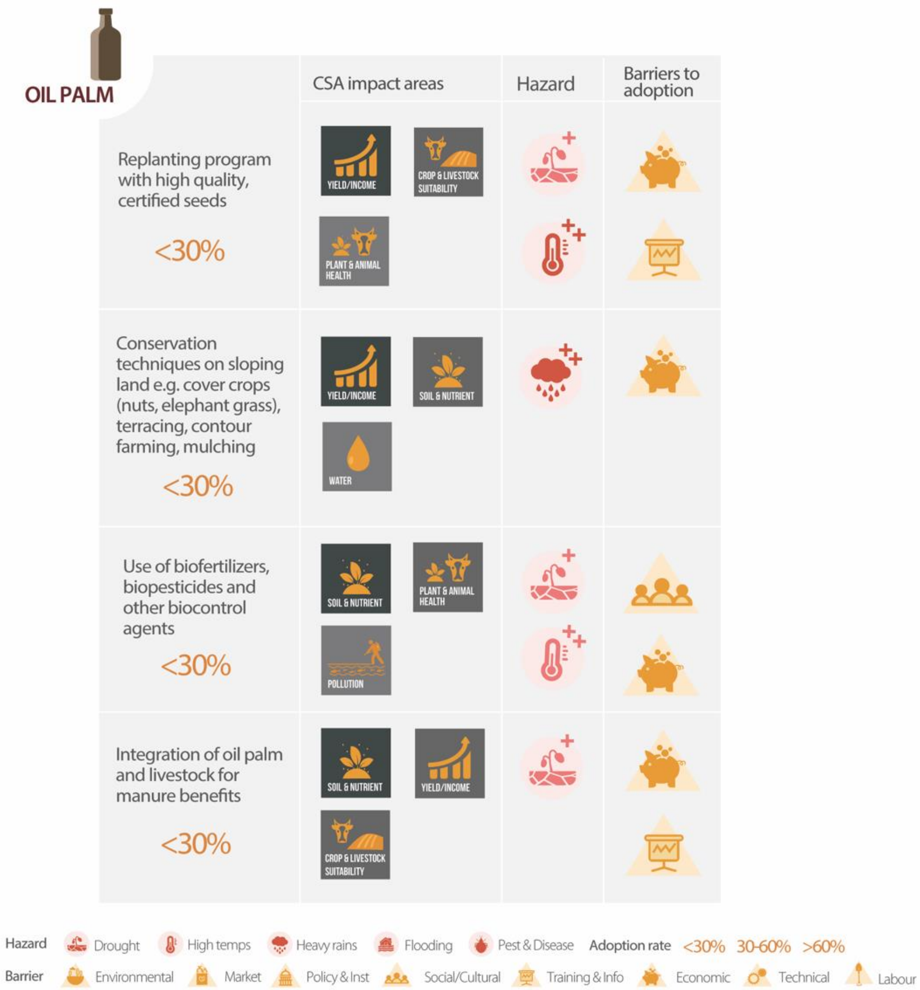
Prioritized on-farm CSA practices & technologies for vegetables



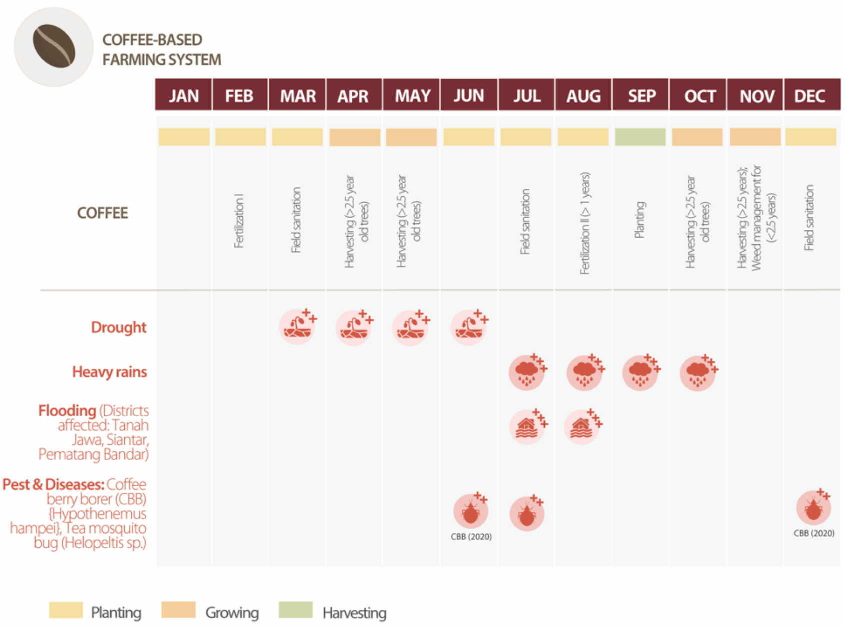
Appendix 2: North Sumatra

Cropping and hazard calendar for oil palm-based system

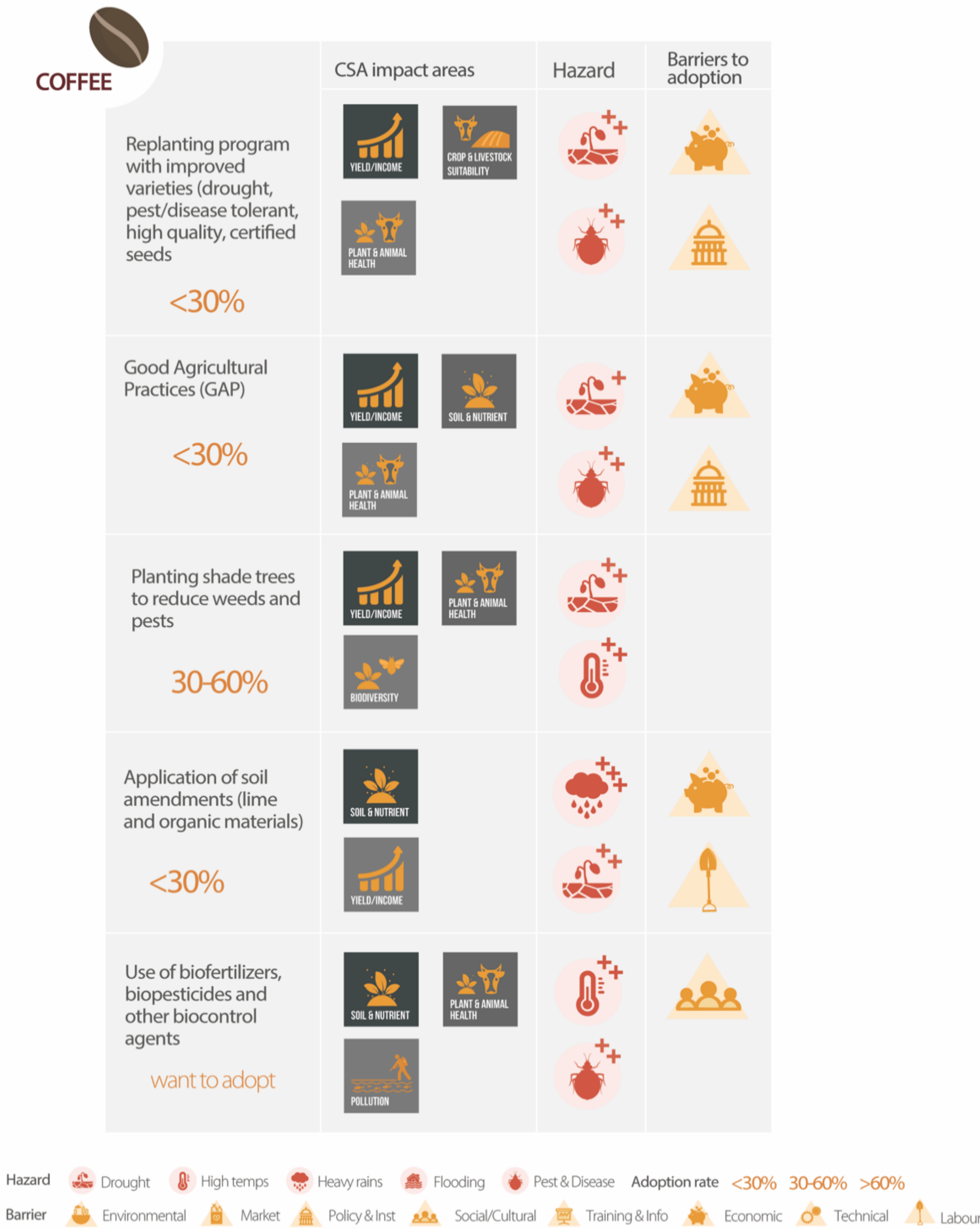
Prioritized on-farm CSA practices & technologies for oil palm



Cropping and hazard calendar for mixed coffee-livestock system

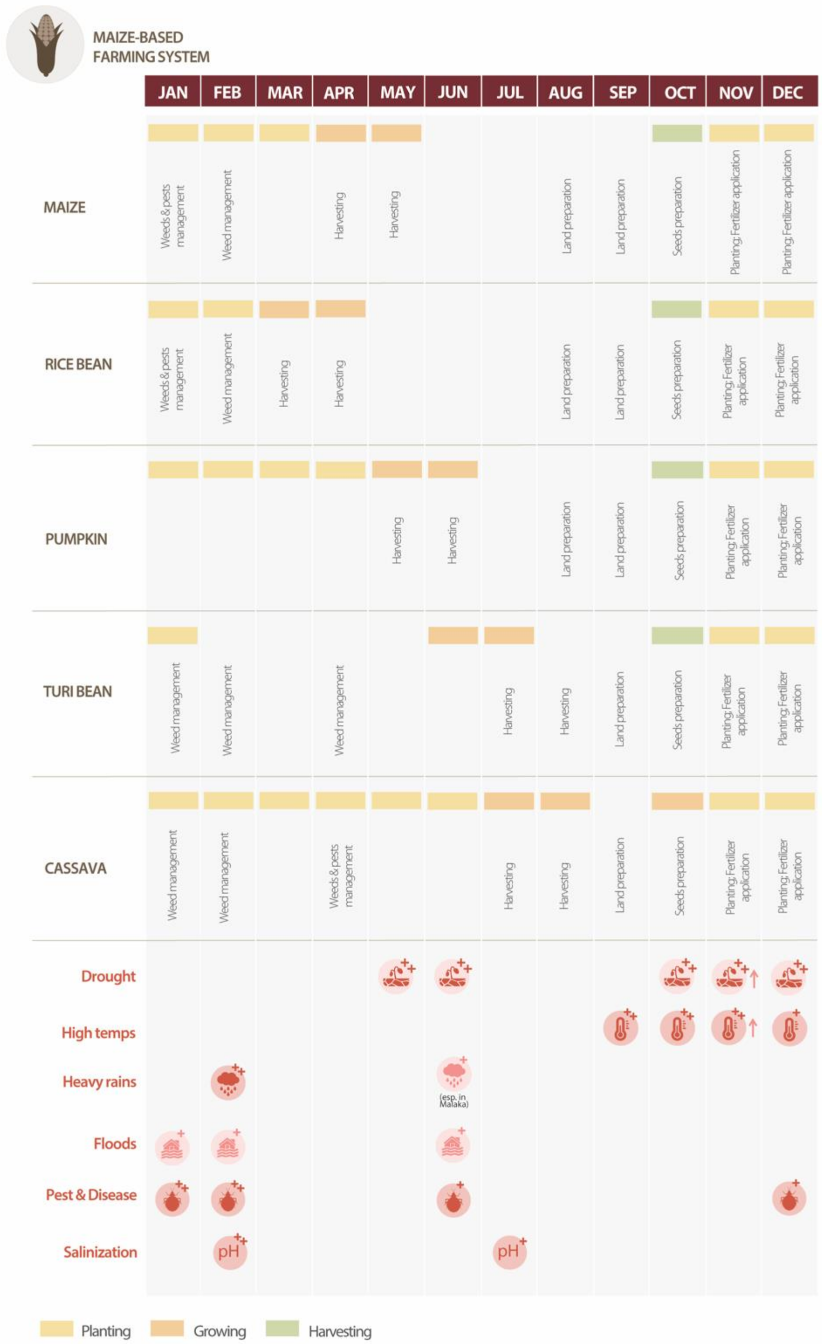


Prioritized on-farm CSA practices & technologies for coffee

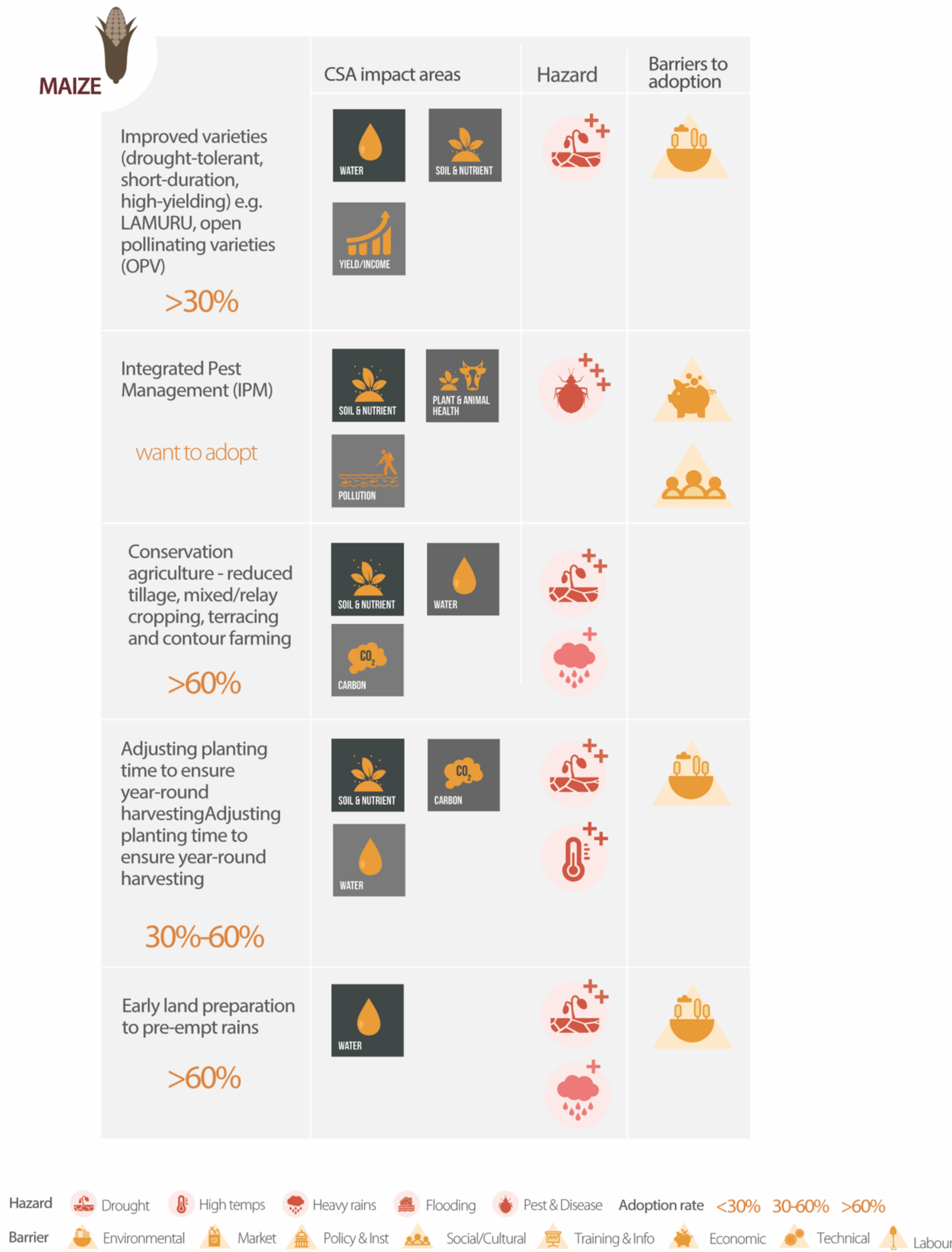


Appendix 3: Nusa Tenggara Timur

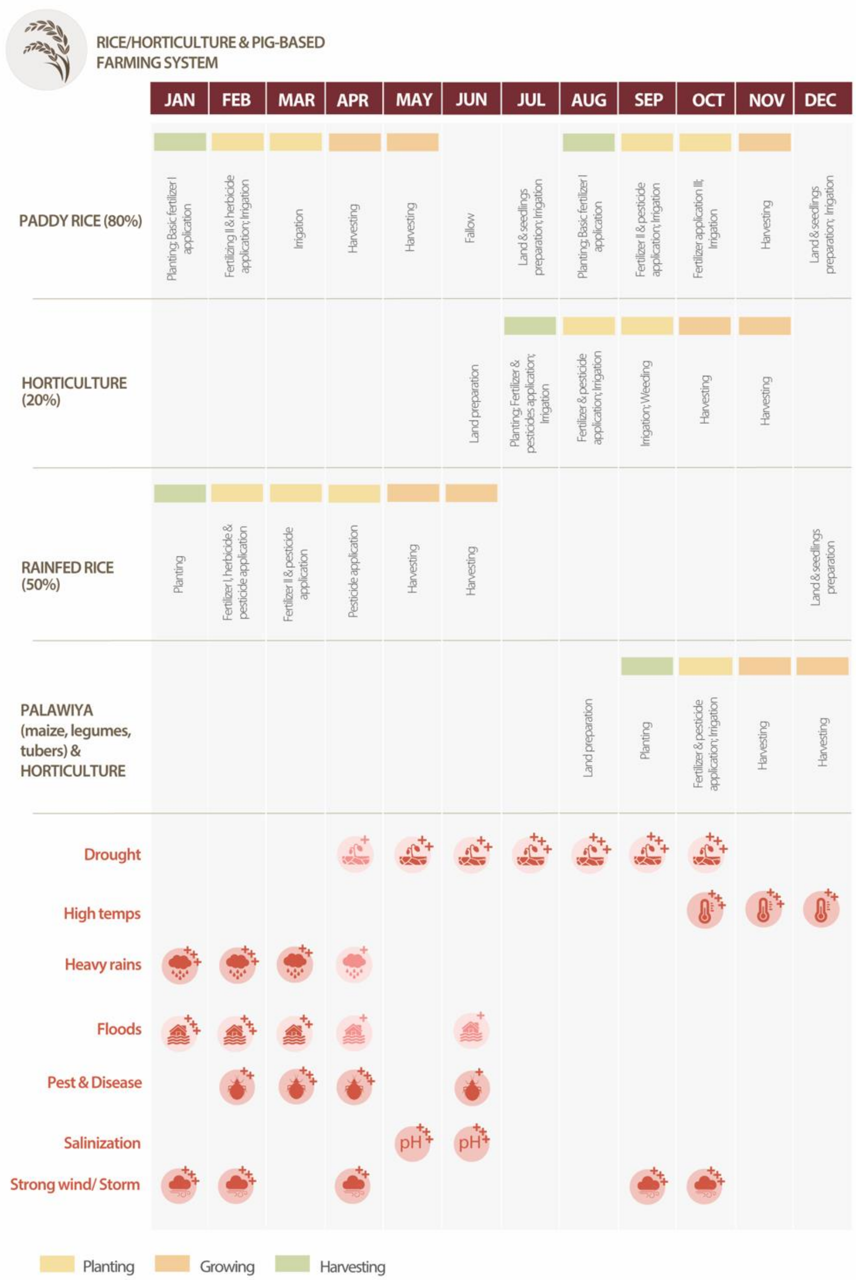
Cropping and hazard calendar for integrated maize-cattle system



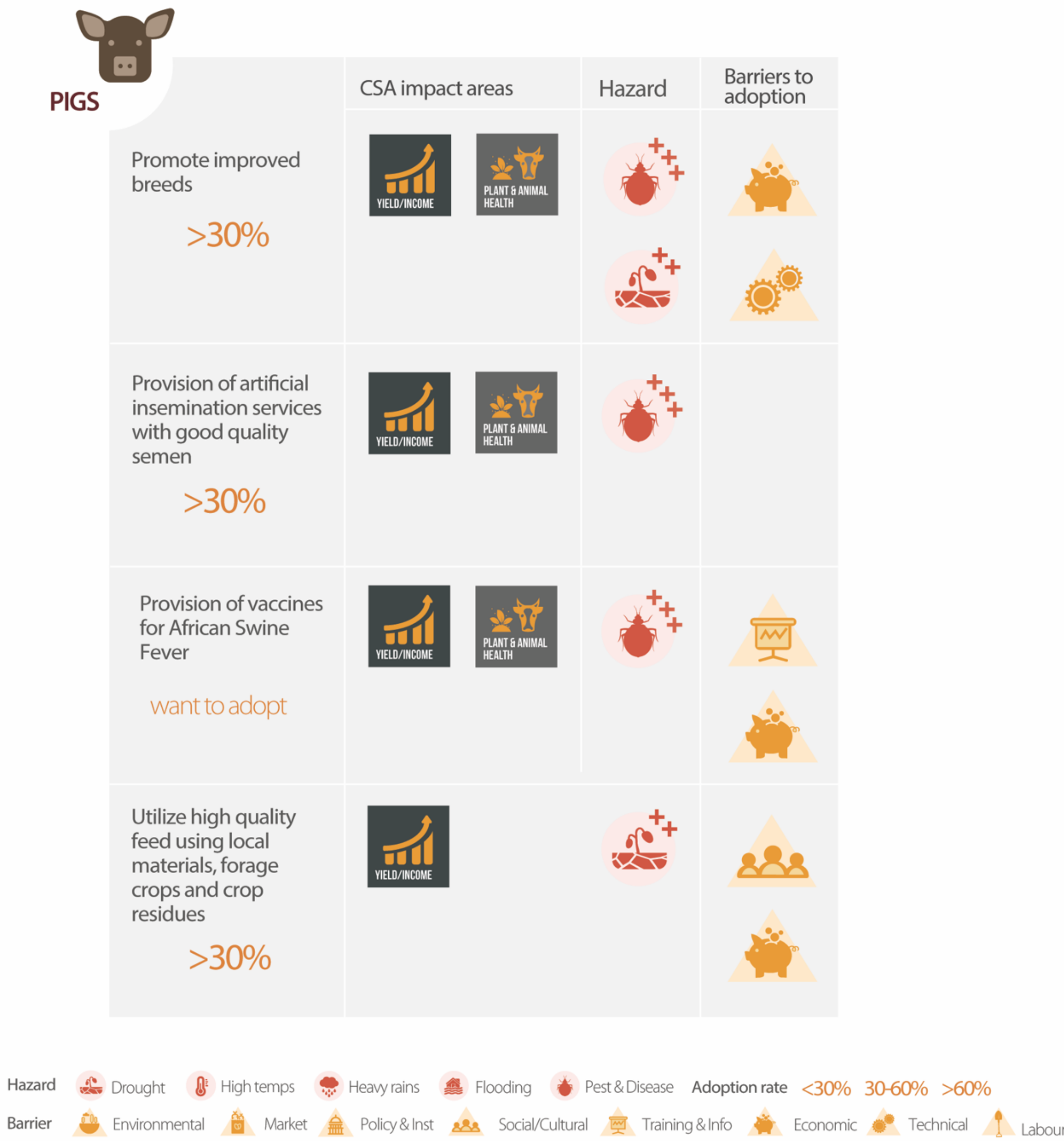
Prioritized on-farm CSA practices & technologies for maize



Cropping and hazard calendar for rice-horticulture-pig system



Prioritized on-farm CSA practices & technologies for pigs



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