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Policy Framework for Myanmar Rice Production and In-Depth Study on Greenhouse Gas Emissions

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ABSTRACT

This study assesses the interactive nature of rice and climate change in the context of Myanmar, one of the largest rice-producing countries. In the first section, special emphasis is given to the current situation of Myanmar's rice production as affected by climate change alongside with possible adaptation strategies. Since only a small share (23.6 %) of the rice area is irrigated, low precipitation climate extremes directly translate into either drought problems due to limited access of water in case of drought or flood problems due to limited drainage. Moreover, more than half of the national rice production derives from the Ayaryewady delta, so that Myanmar's food security is very susceptible to impacts triggered tropical cyclones such as "Nargis" in 2008. The scope of adaptation to climate change is elaborated at different levels ranging technical options for increasing resilience of the rice crop to policies that alleviate risks for farmers.

In the second section, the study provides a quantification and mapping of CH4 emissions, the most important greenhouse gas (GHG) from flooded rice fields. These results are set into perspective of a possible reduction of CH4 emissions through Alternate Wetting and Drying in irrigated rice that has been shown an efficient mitigation strategy in other countries. Myanmar's rice production, however, is dominated by rainfed systems, so the mitigation potential of water-saving irrigation is constrained to 18% of the total emissions from rice production. In turn, other options such as improved straw management will be crucial for lower GHG emissions in rainfed rice areas.

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Introduction

Rice is the food staple in Myanmar while the rice cultivation is the economic backbone for a large share of this predominantly rural population [1]. Myanmar's per capita consumption of rice is about 155 kg rice per year [2] and corresponding to71% of their daily calorie intake which is among the highest rates in the world. The Myanmar government has initiated several production-enhancing policies to strengthening the importance of rice for the economy as a source of employment, food staple, and external revenues [3]. Rice yield levels are affected by both economic factors such as price controls of harvested and traded rice as well as environmental conditions like climate, soil, and availability of water. About a quarter of Myanmar's rice area is irrigated (Rice Division of the Department of Agriculture, pers. comm.) whereas the remainder encompasses rainfed as well as smaller shares of deepwater and upland rice ecosystems. While irrigation infrastructure comprises a certain buffering capacity against climate variability, the non-irrigated areas are fully exposed to droughts as well as floods.

Like other countries in the region, Myanmar is also suffering from the adverse effects of climate change which exerts more and more constraints on agricultural – namely rice production [4]. The government has initially mapped out a National Adaptation Program of Action [5] covering eight sectors including agriculture and water resources. In the agriculture sector, early warning systems and forest conservation are given top priority to cope with farmers' vulnerability to drought, flooding, salinity, heat, other stresses, and extreme weather events. At this point, however, the climate change responses are still fragmented and the country has yet to develop a comprehensive strategy on adaptation and mitigation for the agriculture sector [6]. Under the strategic objective to "enhance the country's preparedness and knowledge on climate smart agriculture practices" the promotion of climate-smart agriculture (CSA) is necessary in boosting production, food security and nutrition in Myanmar [7,8]. Consequently, assessing the available climate change response options is a pre-requisite for efficient policies from local to national scale.

Myanmar ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 as a non-Annex I Party (developing countries without legally binding emissions reductions targets). In turn, Myanmar is required to compile national Greenhouse Gas (GHG) Inventories as part of its National

Communications (NC) and Biennial Update Reports (BUR) on a regular basis according to the calculation guidelines published by the Intergovernmental Panel on Climate Change in 2006 and its refined version in 2019. At this point (Nov. 2021), however, Myanmar has only submitted its first NC in 2012 and not yet any BUR. In terms of mitigation, Myanmar participated in the Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) project, an initial scoping study in 1997 [9]. As part of the UNFCCC process, Myanmar ratified the Kyoto Protocol in 2003 [9] and the Paris Agreement in 2017 and thus, has to specify that specify mitigation goals in form of Nationally Determined Contributions (NDCs) that have recently been updated [10]. While Myanmar's NDC mentions the Agriculture sector with a "*conditional cumulative target of sequestrating 10.4 million tCO2e over the period of 2021-2030*" [10] the underlying actions to achieve this goal focus on the promotion of tree planting and agroforestry. The other sources of sectorial GHG emissions, namely rice production and livestock are not considered in Myanmar's First NDC.

Myanmar's Initial NC quantified GHG emission from rice cultivation at 507 Gg CH_4 for the reference year 2000 [10]. While these values have been adopted by the UNFCCC in the officially released country profile, the reliability of these estimates has to be seen against the backdrop of the global data base of GHG emissions that provide vastly different values for Myanmar rice production in the same reference year, i.e. 985 Gg CH_4 by FAOSTAT[2] and 1283 Gg CH_4 by the EDGAR data base [11]. In fact, the high degree of uncertainty surrounding the GHG estimates for Myanmar's rice production was the main rationale for providing an in-depth assessment within this study. Irrespective of the exact quantities, the undoubtedly high proportion of rice production within the national GHG inventory demands for substantial reductions in this sub-sector to achieve an overall mitigation at national scale.

The objectives of this study are two-pronged, namely
(i) to assess climate change adaptation options through suitable crop management in rice production under given policy settings and
(ii) to quantify and map – for the first time – CH_4 emissions from Myanmar's rice production and assess the scope of possible mitigation through improved irrigation which is widely accepted as the most promising mitigation option in rice production.

Our approach comprises the compilation of relevant documents and data for Myanmar policies on rice by literature search based on internet sources and directly contacting relevant institutions. Moreover, we have compiled a data base on activity data (areas and crop management), and applied GIS technology for mapping the emission results at sub-national scale. As outcome of our study, we envision that stakeholders will be enabled to define effective policies for improved adaptation and low GHG emission that can ensure the sustainable use of natural resources and can ultimately attract private sector investment.

Methodology

Data sources

As outlined above, this article comprises a two-pronged approach which is also reflected in the methodologies applied. The initial section derives from a systematic literature search and 'data mining' of national statistics that have not yet been – in spite of their official nature --made public to an international audience. While the total and the distribution of rice land in Myanmar is well covered in international data bases and resulting maps (see Figure 2), the differentiation of rice ecosystems is typically missing in such international rice statistics or substantially outdated, e.g. data for the early 1990s [12] that are effectively unusable for current conditions. As it is common practice in many SE Asian countries, government agencies use national statistics for internal purposes and national reporting commitments, e.g. NC, but often omit an international publication and documentation and thus, impede a scholarly citation of the source. However, these national statistics comprise important attributes that are not available from international statistics, e.g. the distinction of irrigated vs. rainfed rice per sub-national unit. In turn, any in-depth assessment of both climate change adaptation and GHG emissions will inherently rely on this type of national statistics.

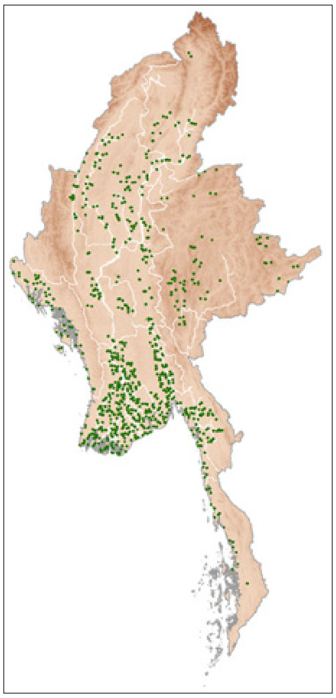

Figure 2: Geographic distribution of rice area in Myanmar, 1 dot = 10,000 ha; source; map adopted from online repository of [16] (https://ricepedia.org/index.php/myanmar).

Table 1: Myanmar rice statistics for 2017-2018; data source: Rice Division of the Department of Agriculture (pers. comm.)

States and divisions	Rainy season						Summer season		
	Rainfed			Irrigated			Irrigated		
	Cultivated area (ha)	Yield (ton/ha)	Fertilizer (kg N/ha)	Cultivated area (ha)	Yield (ton/ha)	Fertilizer (kg N/ha)	Cultivated area (ha)	Yield (ton/ha)	Fertilizer (kg N/ha)
Ayeyarwady	1,519,543	4.2	57.5	0		57.5	556,870	5.8	86.3
Bago	1,108,792	4.6	47.5	0		47.5	113,964	5.4	76.3
Chin	32,022	2.7	76.3	0		76.3	19	4.9	105.0
Kachin	152,401	4.1	76.3	26,508	4.6	76.3	1,984	3.8	105.0
Kayah	20,007	3.3	76.3	13,865	5.2	76.3	1,730	5.3	105.0
Kayin	176,324	4.2	76.3	0		76.3	46,058	4.6	105.0
Magway	128,286	4.2	76.3	137,011	5.1	76.3	26,469	5.3	105.0
Mandalay	68,892	3.6	76.3	160,798	5.4	76.3	69,715	6.0	105.0
Mon	278,814	4.0	57.5	0		57.5	17,014	4.7	86.3
Naypyitaw	36,292	4.7	76.3	32,766	5.5	76.3	11,947	5.9	105.0
Rakhine	446,767	3.7	47.5	0		47.5	219	4.3	76.3
Sagaing	390,683	4.6	57.5	346,798	5.4	57.5	154,443	5.7	86.3
Shan	413,070	4.3	66.9	100,226	6.5	66.9	15,370	6.4	95.7
Tanintharyi	95,745	4.2	57.5	0		57.5	3,574	4.2	86.3
Yangon	474,803	4.0	86.3	0		86.3	77,756	5.2	115.0
Total	5,342,439			817,971			1,097,133		
% of total	73.6 %			11.3%			15.1%		

Source: Rice Division, Department of Agriculture, Ministry of Agriculture, Livestock and Irrigation, Myanmar (pers. comm.)

In our GHG assessment, we used official rice statistics data (2017-2018) at the scale of sub-national units that are called divisions or states in Myanmar (Table 1). We obtained these statistics from the Rice Division of the Department of Agriculture (RD-DA) under the Ministry of Agriculture, Livestock and Irrigation. This departmental rice division prepared these data for their annual report and the Department of Planning that published "Myanmar Agriculture at a Glance, 2018" [13] although this publication misses out many details that can be derived from the original statistics.

Calculation of CH_4 emissions

GHG assessments at national or sub-national scale are typically based on the IPCC guidelines that can be applied through GHG calculators such as EXACT tool [14] or the Cool Farm Tool [15]. The development of GHG calculators has been driven by the desire to provide a readily available tool for users especially those who may not have high familiarity with the IPCC approach. These calculations can also provide information within a policy debate, decision-making on future development, and project proposals. Moreover, such tools have also been applied for generating product/market-oriented information and are often related to C footprint assessments that are in turn often related to specific commodities. To this end, IRRI has developed a calculation tool called Source-selective and Emission-adjusted GHG CalculaTOR for Cropland (SECTOR) which is also based on the IPCC 2006 approach, but has in-build features to make it more user-friendly for scenario-assessments of rice production. The tool can be downloaded jointly with a user manual under https://ghgmitigation.irri.org/knowledge-products/mrv-toolbox. The calculations were based on this tool by using Activity Data compiled in Table 1. In context of rice production in the IPCC guidelines, Activity Data comprises rice statistics on area.

- per season (rainy and dry season in Myanmar),
- per sub-national unit (15 divisions or states in Myanmar) and
- per rice ecosystem which is reflected in the data for irrigated vs. rainfed rice in Table 1.

In the GHG assessment described below, we entered activity data for the 15 sub-national units (divisions or states). This data distinguished between rice ecosystem (irrigated, rainfed) and cropping season (rainy and summer season).

The calculation of methane emissions was done by the following formula adopted from the IPCC 2019 guidelines.

CH_4 Rice=$EF_c \times t \times A \times SF_w$

In which CH_4 Rice annual methane emissions from rice cultivation, kg CH_4 yr

EF_c = baseline emission factor for continuously flooded fields without organic amendments, kg CH_4 $ha^{-1}day^{-1}$

t = cultivation period of rice, day

A = annual harvested area of rice, ha

SF_w = scaling factor for water regime

This formula has been simplified as we assumed a uniform pre-season treatments (SF_p =1) and the absence of organic amendment (SF_o = 1). We assumed a business-as-usual (BAU) scenario of irrigated rice which comprises the IPCC 2019 defaults for Southeast Asia, namely EF = 1.22 kg CH_4/ ha and a cultivation period of t = 102 days. The BAU of rainfed rice had the same values except that we used a scaling factor for water management (SF_w = 0.45) to account for 'regular rainfed' conditions as opposed to SF_w = 1 which was used for continuous flooding in the BAU of irrigated rice.

This scaling factor of regular rainfed was used for the respective figure in Table 1 although we have been aware that this procedure implies a certain bias in input data. Smaller portions of this area comprise deepwater and upland rice, but these lowly yielding systems have drastically decreased in recent decades. This trend was driven by the development toward more productive rice systems, e.g. by introducing short-yielding rice varieties in periodically flooded delta environments [16]. Although statistical data is not available, the current estimates give 11% of the rainfed rice area that could be classified as deepwater and only a marginal share of upland rice (Rice Department, pers. comm.). In terms of GHG emissions, their aggregation under rainfed rice implies that our CH_4 estimates will inherently be at the higher end because CH_4 scaling factors are be zero for upland rice and 0.06 for deepwater rice although the latter has cultivation period that is typically twice as long as in rainfed rice [16].

These input values resulted in seasonal emissions of 124.4 kg CH_4 ha^{-1} $season^{-1}$ for irrigated rice and 67.2 kg CH_4 ha^{-1} $season^{-1}$ for rainfed rice that were multiplied with the respective areas of the subnational units (Table 1). For GIS mapping, we used freely accessible GIS software (QGIS) that can be downloaded jointly with detailed tutorials under https://qgis.org and a shape file for administrative units of Myanmar downloaded from https://www.diva-gis.org.

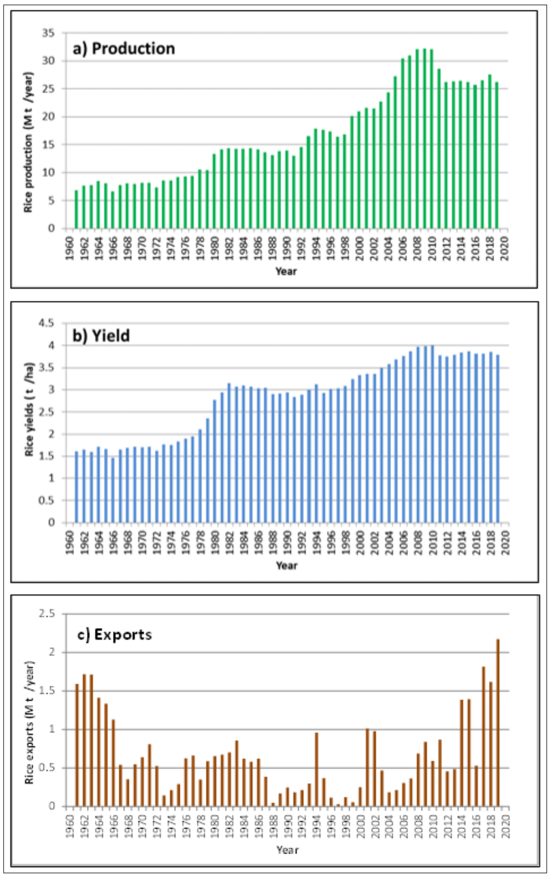

Figure 1a,b: Annual rice production (a), average yield (b) and export quantities (c) of Myanmar from 1961 to 2019; data from FAOSTAT

Results and discussion

Development in the past, present and future projections

This background on information on Myanmar's rice production over the course of recent decades as well as an analysis of the current state and future projection is provided to facilitate a thorough assessment of the role of climate change. The rice area has increased from 7 M t in the early 1960's to 27 M t in recent years (Figure 1a) driven by a yield increase from 1.5 to 3.8 t/ ha (Fig. 1b). While this upward trend was sufficient to catch up with increasing food demand coming from a growing population (from 22 M in 1961 to 54 M in 2019), these growth rates in national rice production are relatively modest against the backdrop of other countries in the region, e.g. Vietnam increased rice production from 9.0 to 43.4 M t in the same period. Back in the early 1960s, Myanmar was the No. 1 rice-exporting country with more than 1.5 M t of milled rice, but the development of rice exports shows a very distinctive, bimodal pattern since then (Figure 1c). After decades of low rice exports – while countries like Thailand and Vietnam showed tremendous increases -- these high export quantities of the 1960's have only recently been reached again.

Table 1 comprises the current rice statistics in terms for irrigated and rainfed rice area pers season and subnational unit. This table also lists data on yields and N-fertilizer rates for documentary purposes although those were not needed in assessing CH_4 emissions. Rice production encompasses the main season planted in June – Aug. and harvested in Nov. – Jan. as well as the dry season planted in Nov. – Dec. and harvested in Apr. – May [16]. Rainfed rice is confined to the rainy season, but comprises 73.6 % of the cultivated area. The most-important sub-national unit is Ayeyarwady Div. in the delta with 28.4% of the rainfed area. Irrigated rice is grown in the rainy and dry season, but with very distinct geographic distribution. In the rainy season (11.3% of total), the main irrigated area is in the North with Sagaing Div. comprising about a third of the area. In the dry season (15.1 %), however, the bulk of irrigated rice is grown in delta region as Ayeyarwady Div. comprises about half of the area. This area can be used is used for rainfed rice without tapping any irrigation water in the dry season.

As for other agriculture-based economies, Myanmar's capability to cope with aggravating droughts will largely depend on irrigation infrastructure. As for the historical development of irrigation, the available data by AQUASTAT[4] provides only values for agricultural land as a whole and not specifically for rice area. In the case of Myanmar, however, it can be assumed that the percentages of irrigated rice area have increased in parallel to the total percentage of agricultural land which increased from1 M ha in the early 1990s to 2.1 M ha in 2004.

While rice production is still constrained by insufficient irrigation systems, reservoir operation needs to be evaluated to divert the water to other sectors for better water resources management. In practical terms, however, the plans have to be seen against the backdrop that the Myanmar government had smaller investment for irrigation development relative to Vietnam [3]. Similarly, the increases in occurrence of droughts will result in crop failure in rain-fed agricultural areas and will increase the demand for irrigation [9]. Besides, village ponds and farm dams for rainwater harvesting are the common systems during the monsoon season for improving water supplies for their crops and livestock in the summer season in many places of the major rice growing areas of Myanmar [6].

Consequently, Myanmar government water vision states "By the year 2030 the country will have an attainment of sustainability of water resources to ensure sufficient water quality of acceptable quality to meet the needs of people of country in terms of health, food, security, economy and environment" [17]. [18] also mentioned that the rationalization of the irrigation system requires the combination of several technical and institutional measures, including improved and participatory design, monitoring and evaluation of performance, research and measurement on water use efficiency, evaluation of alternative irrigation systems (surface, groundwater, drip, sprinkler), water-saving irrigation practices such as Alternate Wetting and Drying (AWD), System of Rice Intensification and close integration with agronomic practices and the opportunity of diversifying away from rice.

Exposure to cyclones

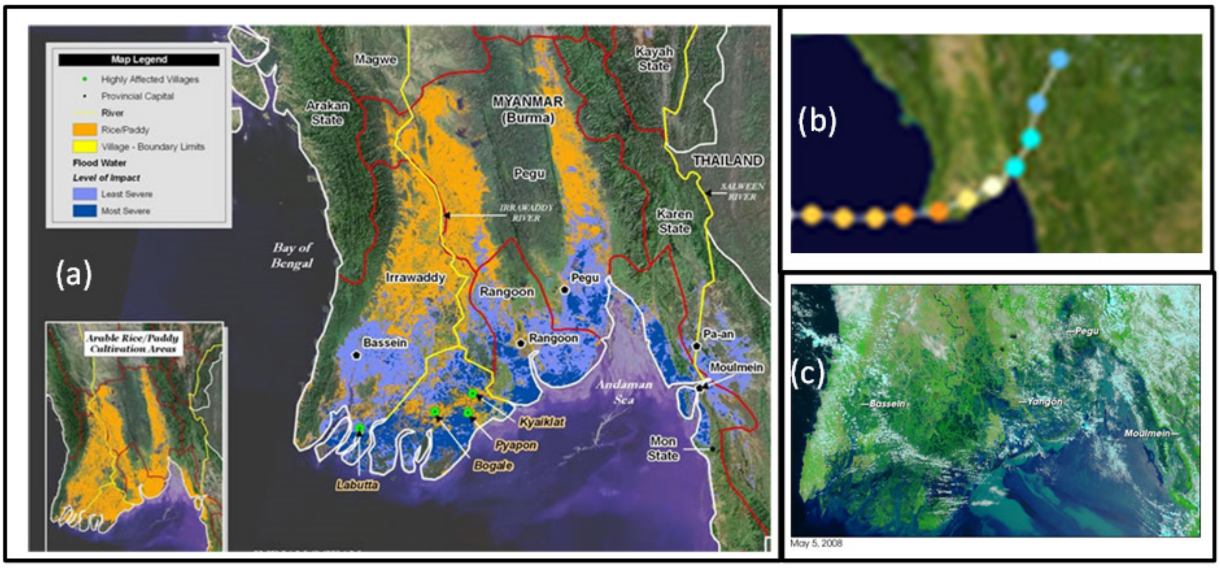

Figure 3: Impact of Cyclone Nargis in May 2008, Sources of figures: (a) USDA Foreign Agricultural Service Office of Global Analysis IPA Division , (b) [19], The color scheme uses the Saffir-Simpson Hurricane Wind Scale. Yellow to Orange to Red: category 1 to category 5 tropical cyclone (winds from 119 to >252 km/hr; The colored points show the location of the storm at six-hour intervals; c) NASA/MODIS Rapid Response Team cited in [20].

As can be seen in Figure 3a,b,c, the Ayeyarwady River delta is highly susceptible to flood and salinity intrusion triggered by tropical cyclones, of which the most devastating has been cyclone Nargis in May 2008 [20]. The impacted went far beyond the actual coastline and caused flooding in landscapes that are up to 7 m a.s.l. as flooding was exacerbated by the heavy rainfall coinciding with the surge coming from the ocean [19]. While tropical cyclones are not a new phenomenon as such and affected coastal areas long before the advent of climate change, current research clearly points toward an aggravating effect by rising temperatures. A recent IPCC Report stated a high probability of of increasing Tropical Cyclone intensities as well as frequencies over the past 40 years [21].

Cyclone Nargis devastated Myanmar's 'rice bowl' in the Ayeyarwaddy (Irrawaddy) Delta causing an estimated 1.2–million-ton drop (6%) in rice production, jeopardizing the country's food security and exports [22]. The cyclone affected about 1.75 million ha of rice fields corresponding to 30 percent of the standing crop at national scale in the rainy season . The impacted area encompassed the divisions of Ayeyarwady (800,000 ha), Yangon (450,000 ha), Bago (250,000 ha) and Mon (250,000 ha). These estimates based on Remote Sensing were largely confirmed by MOALI that estimated that roughly 1.6 million hectares of rice fields were damaged by cyclone Nargis. Since large swaths of these rice fields were inundated with salt water, the detrimental impacts of salinity were also discernable in the ensuing season.

Policy framework

Myanmar's policies are formulated within the context of plans and regulations that include the National Economic Policy, the Framework for Economic and Social Reforms, Myanmar Comprehensive Development Vision, the National Comprehensive Development Plan, the Foreign Investment Law, and the National Export Strategy. Each of these documents, although addressing general issues and not being specific to agriculture, contain several important implications for agricultural development. Besides, the vision statement of the agriculture policy reads as follows: "by 2030, Myanmar achieves inclusive, competitive, food and nutrition secure, climate change resilient, and sustainable agricultural system contributing to the socio-economic well-being of farmers and rural people and further development of the national economy" [19].

The policies under Ministry of Agriculture, Livestock and Irrigation (MOALI) are structured under the following topics [13]:
a. Land Use and Management
b. Water Use and Management
c. Agricultural Financing
d. Agricultural Mechanization and Input Sector
e. Cooperative Enterprise and Cooperative System Development
f. Rural Infrastructure Development
g. Research, Development and Extension
h. Marketing and Value-added Processing and Export
i. Governance, Institutional and Human Resource Development
j. Environmental Conservation and Climate Change Resilience.

Other agricultural related strategies and plans that have been formulated in recent years include the: (i) Five Year Plan 2016-17 to 2020- 21: (ii) Myanmar National Action Plan for Food and Nutrition Security; (iii) Myanmar Climate Smart Agricultural Strategy; (iv) Myanmar Rice Sector Development Strategy; (v) White Paper from Rice Bowl to Food Basket; (vi) White Paper Vegetables; (vii) Food Value Chain Road Map; and (viii) Agricultural Sector Policies and Thrusts for Second Five Year Short Term Plan of MOALI (October 2016) [19](MOALI, 2018).

The agriculture sector of Myanmar agriculture has experienced only limited improvements in terms of drainage and land development. In the Ayeyarwaddy delta, farmers have effectively no other option than growing rice. Change from a rice-centric policy to diversified food production systems will require significant investment in water management, particularly in low lying areas and the delta [18]. Although 84% of the agricultural land of Myanmar is not irrigated, the specific features of rainfed farming systems and soil and water management practices and technologies are not sufficiently researched, demonstrated or disseminated. Furthermore, in the Ayeyarwaddy delta, Bago, and Sittaung delta, large rainfed areas that require only drainage are underutilized [18] (MOALI, 2018).

Risk Management

Building resilience of farmers to climate change and disasters will require the combination of adaptation measures at the household, community, and national level. Landscape-based measures to promote Community Based Disaster Risk Management will help farming communities to be better prepared to respond to risks such as flood and drought through structural protection infrastructure, reservoirs, drainage, safe areas and non-structural measures (eg rain water harvesting, crop diversification, early warning system, emergency kits). Early Warning Systems will be strengthened to provide adequate lead time for communities to respond effectively to drought, heat waves, flash flood, dam spillage, and flood. Preparedness system at the community or region/state level might include food and seed reserves.

Ideally, crop and livestock insurance could present an efficient safety measure for farmers to prevent or at least limit financial losses and potential risks to food security [18]. At present, there is no crop insurance policy in Myanmar. Although some companies claim that they have been practicing crop insurance, this is often done in the context of selling agrochemicals in response to crop losses due to flood, drought, pests and diseases [23]. In terms of infrastructure development, the best risk management option is to expand access to irrigation, coupled with investments in drainage [24] which has been discussed above.

Government Subsidies and Policies

The Myanmar Agricultural Development Bank (MADB), a government enterprise, provided the limited seasonal crop production loans to farmers totaling about 1.7 trillion kyats (US$ 1.12 billion) in the 2018/19 crop season which is about 13% more than in the preceding year. As for individual rice farmers, MADB provides a loan of up to 150,000 kyat (US$115) for a maximum of 10 acres with an interest rate of 8%. Moreover, farmers can also apply for loans under a four-year program (more than 130 million USD), under a 4-year project (2017/18-2020/21) implemented as Japan-Myanmar collaboration. Other options for loans are the Myanmar Economic Bank, local cooperatives, the Myanmar Rice Federation (MRF), and various non-governmental organizations [25].

MRF announced a reference price of US$189/ MT (MMK 250,000/ MT) for paddy with the industrial standard of 14 percent moisture content, which meets certain minimum quality criteria, on March 6, 2018 during the Myanmar Rice Stakeholder Forum in Naypyitaw. If the market price is lower than the reference price, MRF offers to pay the higher reference price rate, with presumed support from the MOALI [25].

As shown in other countries, the formation of self-organized cooperatives can play a pivotal role in improving farmers' livelihoods through better integration into the supply chain. However, the main issue is to maintain the sustained functioning of these organizations in the long run. However, it is a widely accepted fact that government support will be crucial for forming organization in line with the procedures of cooperatives.

For policymakers seeking a quick and easy means of helping agricultural producers in Myanmar, an appropriately valued and stable exchange rate-combined with falling inflation-would be extremely effective [26]. The fiscal budget for agriculture is mainly allocated to the central government which results in low efficiency in terms of tangible impacts. One promising policy in the Myanmar context is decentralization by increasing the agricultural budgets of local governments, especially in the area of irrigation development [27].

Seed Systems

Most of Myanmar's rice farmers use their own seed from season to season. On the other hand, the government has established a national seed certification system that regulates and promotes the production of purified and vigorous seeds of high-yielding varieties. While the private seed sector is poorly developed, a well-managed public sector seed system is essential for disseminating improved rice varieties. Once certified varieties are made available to farmers, the seeds can be readily multiplied and distributed through informal farmer-to-farmer mechanisms. But those varieties have to fit to local specifications in terms of soils, water availability and climate, so a nation-wide varietal evaluation system must be linked to seed production and distribution programs [24].

Responses through Climate-smart Agriculture

Climate smart agriculture (CSA) is based on three pillars, namely (i) food security, (ii) adaptation of agriculture to climate change, and (iii) mitigation of GHG emissions. The overall goal is supporting farmers' readjustment and reorientation to the challenges of climate change, hence the importance of integrating CSA technologies and practices with Good Agricultural Practices (GAP) to help increase and sustain farm productivity [6].

Improved management of the rice crop

Given the ramifications in potential crop management strategies, we compiled the different options of climate-smart agriculture in a tabulated form (Table 2) to achieve a more structured presentation. This table lists all stages of rice cultivation from seed production to harvesting jointly with the respective CSA options. In terms of mitigation efficiency, improved irrigation management, namely Alternate Wetting and Drying, has the largest potential to reduce emissions, but this management practice has rather limited applicability in Myanmar rice production that is dominated by rainfed area (see above). All the other CSA options, however, are in principle possible in both, rainfed and irrigated rice. However, as the Myanmar agriculture sector is generally characterized by low inputs of fertilizer and pesticides, the mitigation potentials through increasing resource use efficiencies of these inputs are rather limited.

Table 2: Stage-specific assessment of Myanmar's rice value chain in terms of current practices and potential CSA interventions

Stage of cultivation	Current status of Myanmar's practices	Potential CSA interventions
Seed production	The state-run seed system in Myanmar is insufficient to supply seeds of improved varieties to farmers. The formal seed multiplication chain analysis of Myanmar shows that limited involvement of the private seed sector was found. Private companies are involved in the last step of multiplication. At the seed farms there is much pressure on producing the targeted quantities of rice, while there are limited incentives to produce quality seed or experiment with new varieties.	Good seed quality is one of the pre-requisites for high yields and thus for the CSA pillar "Food Security". Myanmar also has ambitious plans to improve seed systems it seems obvious that support from international projects will be instrumental in achieving this objective.
Variety selection	Under an unfavorable rainfed environment, many rice areas in Myanmar are exposed to hazards such as rainfall-induced floods, sea-level rise, salt-water intrusions, and drought. Farmers in these areas are growing single rice crops per year.	To help mitigate losses due to abiotic stresses, IRRI has developed submergence-, saline-, heat-, and drought-tolerant rice breeding lines. Combining Saltol and SUB1, DroughtTol and SUB1 in one genetic background seemed feasible with no apparent negative impacts on agronomic traits.
Crop Establishment	The common practice of Myanmar farmers is to plant longer maturity rice variety during the monsoon season and either leaves the field fallow or planted another shorter maturity season crop during the summer or dry season.	The adaptation of stress tolerant, high yielding and shorter maturity wet season and summer season rice varieties, as output of the participatory varietal selection (PVS) trials by the International Rice Research Institute projects that are most preferred by the farmers, can now be used to adjust the cropping calendar to cope with flooding or submergence during the monsoon season and salinity or drought during the summer season. Adjusting crop establishment will be an efficient strategy to cope with flooding and drought. This encompasses methods of conventional practice of transplanting and direct seeding, both of which can be done on wet and dry soil. In this regard, seedbed and land preparation are crucial in cultivating crops that will generate high growth and productivity. GHG emissions are reduced through the use of machine transplanting because of a reduction of cultivation time and improving water-use efficiency. It is most effective in combination with laser land leveling, which reduces the amount of time and volume of water needed for irrigation. Through a better plant establishment, a higher yield quantity can be achieved, which is resulting in a lower emission per yield unit
Crop Management: Nutrient Management	Myanmar imports about 85% of its chemical fertilizer from China and Thailand and produces domestically 15% of the fertilizers used. As the price of chemical fertilizer is still not affordable to many farmers, fertilizer application is still low for national average. Existing fertilizer recommendation for 1t/ha (~405 kg/acre) of rice grain in Myanmar is about 40 to 50 kg/ha of N, 20 kg/ha P_2O_5 and 30 kg/ha K_2O (~16-20 kg/acre N, 8 kg/acre P_2O_5 and 12 kg/acre K_2O). The usual farmers' practice with imbalanced fertilization, or application of urea to rice crops, and no application of fertilizer in pulses resulted in yield decline in both rice and pulses.	Proper nutrient management is a pre-requisite of high resource use efficiency. Over-fertilization is very rampant in many parts of Asia and it is at risk of also becoming prominent in Myanmar. On the other hand, there is under application of fertilizers, in both cases resulting in inefficient fertilizer management. Site-specific nutrient management allows farmers to optimally apply right amounts of essential nutrients when needed. It also reduces GHG emissions as more efficient use of nitrogen reduces nitrous oxide (N2O) emission from the field and indirect emissions during the production of N-fertilizer
Crop Management I: Water Management	Only about 6% of total water resources are being utilized by rice annually [7]. AWD has also been mentioned in Myanmar's Nationally Determined Contribution (NDC) which ensures alignment to broader policy goals.	While the mitigation benefits of AWD will be discussed in PART 2, this irrigation water management is a key in developing drought resilience and mitigation of methane emissions. AWD is already a familiar concept to policy makers and the general public, so its application is often seen emblematic for CSA in rice. With AWD, the field is alternately flooded and non-flooded. The number of days of non-flooded soil in AWD between irrigations can vary from 1 day to more than 10 days. Root growth is also promoted and tended to tolerant lodging.

Crop Management II: Pest Management	Pesticides are still rarely used compared to countries like Vietnam, Thailand, China and India [23]. The lack of knowledge of farmers on proper pesticide handling and use was a matter of concern.	With the onset of climate change, suppressing pest populations and diseases has been a key challenge in farm production. The rapid changes and extreme weather conditions including temperature, wind, precipitation, humidity and drought influence the presence of pests. Treatment through pesticides is a common response to this particular problem, however for the case of agriculture, its application must be managed—it has to be both safe and environmentally sound.
Rice Harvest and Straw Management	Open burning, agriculture and land clearing activities, like rice straw burning, are still being practiced in rural areas of Myanmar. According to a socio-economic survey conducted in Tawnte Township located in Yangon division, nearly 70% to 80% of the local community usually practices open burning for the various reasons, such as waste burning and land clearing activities [28]. As an alternative to rice straw burning, the Union of Myanmar government, other private groups and NGOs initiated some projects of making rice straw as substrate for agriculture and industrial purposes (e.g cattle feed from the delignification of rice straw, for cattle feed, animal feed completing feed block from rice straw, paper making, mushroom production).	Rice harvesting needs to be done in the most efficient way, while addressing the labor shortage in Myanmar. In recent years, the country is transitioning to mechanized harvesting and land preparation to optimize labor productivity. There are several available ways to use rice straw instead of disposing or burning it. Rice straw can be collected mechanically and may be used as a substrate for growing mushrooms. It can also be processed into silage for cattle feed. It can also undergo anaerobic digestion to generate fuel that can that can be used for cooking. The rice straw when allowed to decompose with animal manure can be used as organic amendment to the rice field.

Crop Diversification

Crop diversification is a strategy that alternates planting cycles of several crop varieties. It is intended to provide broader choices in the production of a variety of crops in any arable land, to help expand production-related activities in various crops. It can improve resilience in a variety of ways and provide economic benefits. This includes: a) provision of alternate host and ability to break pest and diseases build up which may worsen under future climate scenarios, b) by protecting crop productivity and supply from the effects of greater climate variability and extreme events and c) increased production and food nutrition.

Rice-rice and rice-pulse (or upland crops) systems in Myanmar are of growing importance under a changing climate. Growing rice during monsoon season and followed by rice or non-rice crop (i.e. green gram, black gram, peanut, etc.) during the dry season is a common practice in the Ayeyarwady and Bago Regions. The rice-pulse system is commonly practiced in Delta region (Ayeyarwady, Bago and Yangon regions), partially irrigated dry zone (Sagaing, Mandalay and Magway Division) and coastal region (Mon, Rakhine states and Thanintharyi Division) [7]. Pulses can contribute significantly to increasing productivity and improving the sustainability of rice-based cropping systems.

Certification of sustainable rice production

At this point, Myanmar has not yet embarked in any national program for labelling of sustainable food products. As an international organization, the Sustainable Rice Platform (SRP) has initiated activities in Myanmar that include reducing the social, environmental and climate footprint of rice production. The SRP is a global multi-stakeholder alliance has over 100 institutional members from public and private sector stakeholders, research, financial institutions, and NGO. The SRP Production Standard promotes resource-use efficiency and climate change resilience in rice systems-both on-farm and throughout value chains- and pursues voluntary market transformation initiatives by developing sustainable production standards, indicators, incentive mechanisms, and outreach mechanisms to boost wide-scale adoption of sustainable practices throughout rice value chains. The first standard encompasses 12 performance indicators of that squarely confirm with principles of climate-smart rice production including high resource efficiencies and low GHG emissions [29].

Comprehensive approaches in climate change projects (in collaboration with international organizations)

In collaboration with MOALI, the International Institute for Rural Reconstruction has established several Climate-smart Villages in Myanmar [30,31]. The research is designed to further generate evidence and new knowledge on the role of local platforms in supporting climate change adaptation in agriculture. Under the umbrella of Climate Change Agriculture and Food Security (CCAFS), International Institute for Rural Reconstruction studies the contributions of CSVs and climate-smart agriculture (CSA) in enriching local food systems for better nutrition, enhancing livelihoods, gender equity and inclusion, and increasing household resilience. The study will also explore how CSA promotion results in women's economic empowerment and to what extent it affects local food systems in agriculture-based study communities. The different CSVs focus on the following CSA interventions:

- Sakta, Chin State: Improving legumes, recycling of organic matter, intercropping and crop rotation, and the inclusion of small livestock
- Taungkhamuak, Shan State: Agroforestry, Small scale native livestock project, Upland rice, corn and millet
- Htee Pu, Mandalay Region: Dryland horticulture, recovery of sorghum and pigeon pea cultivars, homestead agroforestry and small livestock
- Masein, Ayeyarwady Region: Multi storied cropping systems in homestead areas, Small livestock production, Indigenous fish species conservation and intensive betel vine systems

The ongoing Climate Smart Rice Project by the SRP promotes sustainable rice-growing practices with the goal of reducing vulnerability to climate change and natural disasters. The project will target 4,000 smallholder farmers around Mandalay, southern Shan, Mon and Bago over the coming three years, working closely with the Government of Myanmar and the agri-business sector. The project is funded by the Norwegian Agency for Development Cooperation (NORAD) and the Swiss Agency for Development (SDC) and implemented by a consortium of partners including

SRP, Helvetas Myanmar and PRIME Agri Group. Endorsed by the Parliamentary Committee for Agriculture, Livestock and Rural Development, the project encompasses standards and practices have been shown to boost make crops more water- and fertilizer-efficient and improve resilience to climate change impacts.

Capacity building climate change policies was spearheaded by IRRI through the PIRCCA project (Policy Information and Response Platform on Climate Change and Rice in the ASEAN and its member countries) that was implemented in Myanmar through collaboration with Yezin University. In terms of practical implementation of climate-smart agriculture, IRRI developed a set of training manuals and brochures in Myanma language alongside with training courses which were funded by UNEP.

In-depth study on GHG emission

Anthropogenic greenhouse gas emissions from the agriculture sector amounting to an estimated 500 million tons CO_2e/ year. Rice is a major contributor of the GHG methane which is emitted from flooded soils and is also a source – though to a lesser extent - of N_2O from fertilizer application. Rice production also involves CO_2 emissions from fossil fuel consumption in the rice value chain and the production site of fertilizer and pesticide inputs [30]. However, according to the IPCC guidelines for national GHG inventories these CO_2 emission sources are allocated to the energy and industrial sectors, but not under the figures given for agriculture of the respective country. Moreover, the GHG budget also has to take into account what happens to the rice straw. In spite of manifold efforts to prevent open field burning, this practice is still prevailing in most parts of SE Asia [32] and is also the most common form of straw management in Myanmar [28]. It should be noted tough, that – in spite of detrimental effects on the local air quality – open field burning is not a large source of GHG. This may sound counter-intuitive, but the release of CO_2 from straw burning is not considered a net-flux as it only concludes the annual carbon cycle that has started through photosynthesis of the rice plant of few months before the actual burning. On the other hand, open field burning releases smaller amounts of the GHG CH_4 and N_2O through incomplete combustion [33].

In totality the GHG budget of rice production is largely dominated by CH_4 from flooded fields. Although the exact percentage will depend on cultivation practices and postharvest technologies, the share of CH_4 roughly corresponds to two thirds of the 'on-field' emissions and about half of the total emissions throughout the entire value chain including resource inputs [30]. Given this dominance we consider it justified that the following assessment of GHG emissions in terms of spatio-temporal distribution and possible mitigation focuses on CH_4 only to provide a proxy for GHG emissions as a whole. By the same token, we wanted to set our newly computed results into the context of previous GHG estimates of Myanmar rice, which inherently requires the same system boundaries as in those national and international GHG calculations limited to CH_4 from flooded soils. Finally, we also see a strong rationale in focusing on rice only, because it is responsible for 10% of all agricultural GHG emissions worldwide and up to 50% of agricultural emissions in some rice-producing countries including Myanmar (see below). In turn, targeting CH_4 emissions from rice fields can make a significant contribution to Nationally Determined Contribution (NDC) targets of rice growing countries.

Quantification of BAU scenarios

The calculated value of GHG emissions from Myanmar's rice production is 597 Gg CH_4/ year which is about 20% higher as the 507 Gg CH_4 given in Myanmar's First NC [11]. In contrast, estimates given in the international emission databases are considerably higher than our result, namely 985 Gg CH_4/ year by FAOSTAT and 1283 Gg CH_4/ year by the EDGAR data base . While it is not immediately clear what caused these discrepancies, we see the most likely reason in the different activity data, in particular the distinction between irrigated vs rainfed rice in the national statistics as opposed to the rice statistics available at global scale do not specify the areas of these rice ecosystems. As indication for the plausibility of this argument we refer to the fairly congruent emission estimates for countries that have only a minor share of rainfed rice, i.e. Vietnamese rice production has been quantified to 1790 Gg CH_4/ year by the Vietnamese Government in its most recent Biennial Updated Report [34] vis-à-vis 1337 Gg CH_4/ year by FAOSTAT and 1804 Gg CH_4/ year by EDGAR for the same reference year (2014).

This wide range of estimates in the CH4 sources strength is further compounded by the use of different Global Warming Potentials of CH_4 (GWPCH4) that is needed for calculating the share of rice production in relation to the agriculture sector and total emissions. In the Myanmar NC, the use of $GWPCH_4 = 21$ results in 10,652 Gg CO_2e corresponding to 47% of the emissions from the agriculture sector. In relation to total emissions, this amount corresponds to 31 % as long as the carbon sequestration by land use, land use change and forestry (LULUCF) are disregarded which the common approach for inter-comparison of national GHG inventories. While these values from the Myanmar NC have been adopted by the UNFCCC in the officially released country profile , it should be noted that the recent literature indicates a GWPCH4–value of 28 - 36 [35]. To assess the impact of an updated GWPCH4-value we have re-calculated the NC figures based on a value of 28. Given a 68% share of CH_4 (from all sources) in relation to the total emissions [11], total emissions will increase from 33,997 to 40308 Gg CO_2e. Subsequently, the share of our calculated value from rice production translates to approximately 35 % from the total as opposed to 31 % given in the First NC. It should be noted that the share of rice within the agriculture sector will only marginally be affected by the $GWPCH_4$ because CH_4 is responsible for the bulk of agricultural emissions. But if we add the increment coming from our estimate for rice production (Δ = 90 Gg CH_4), the calculated share would be at 39% of the total Myanmar GHG emissions.

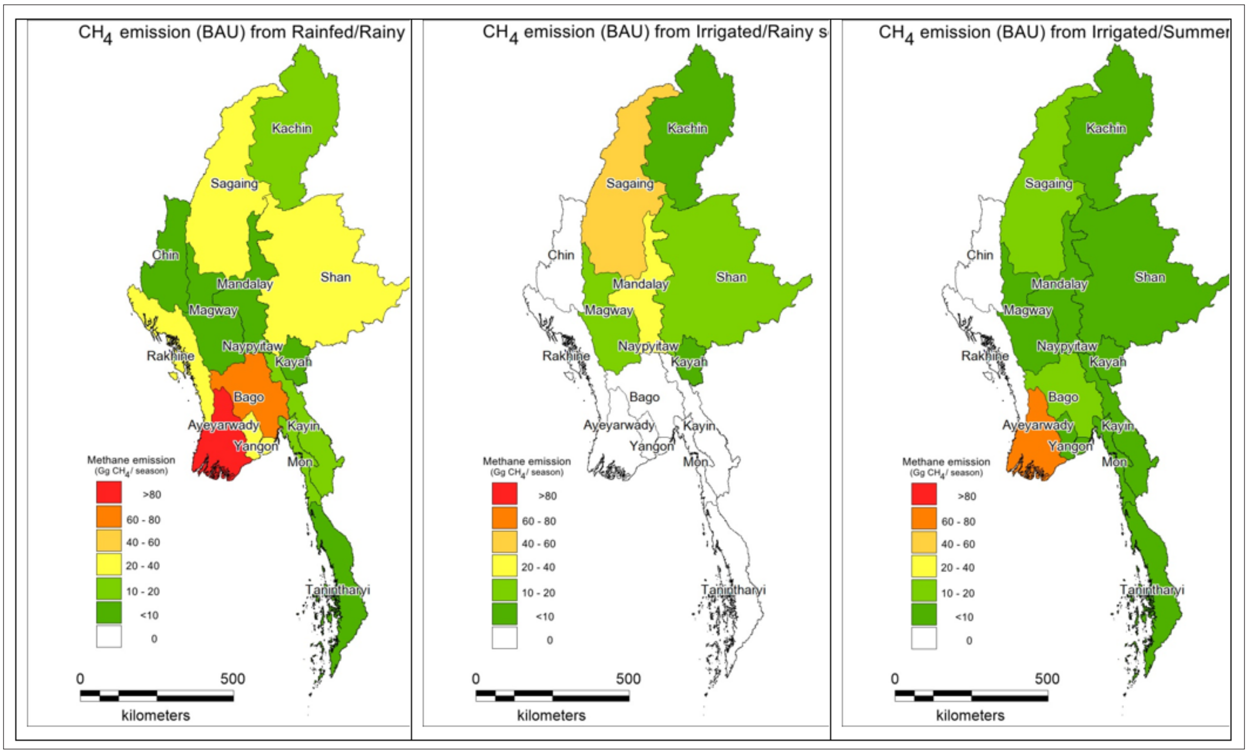

Figure 4a,b,c: GHG emission under BAU scenario from (a) rainfed rice in the rainy season, (b) irrigated rice in the rainy season and (c) irrigated rice in the summer season

Geographic distribution

Figure 4a,b,c illustrate the geographical distribution of GHG emission from rice at the scale of divisions/ states under the BAU scenario. Given the calculation procedure, the geographic patterns reflect respective rice area of the mapped rice system and season. The rainy season is the main growing period because rainfed rice can be grown in most parts of the country. The largest GHG emissions are attributed to Ayeyarwady division (> 80 Gg CH_4/ season) and its neighboring Bago division (60- 80 Gg CH_4/ season) (Figure 4a). But even for the other sub-national units the CH_4 emissions from rainfed rice are higher than for irrigated rice irrespective of the season and in spite of the low Scaling Factor for rainfed rice (SF_w = 0.54).

Figure 4b shows emission from irrigated rice in the rainy season when the respective areas per unit are relatively small. While emissions are very low or moderately high in most units, the division of Sagaing has highest emissions (40-60 Gg CH_4/ season). The map for summer season rice (Figure 4c) when rice production is constrained in irrigated land shows low emissions for almost the entire country except for Ayeyarwady division (60-80 Gg CH_4/ season).

Possible GHG mitigation

AWD is a water-saving technology that has been developed to save irrigation water and that has a shown track record to reduce CH_4 emissions [36]. The AWD practice comprises flooded and non-flooded period following a protocol that avoids drought stress for the plants and ensures high yield levels. As this technique has been developed for irrigated rice, its implementation under the inherently unreliable water supply of rainfed agriculture implies large risks. On the other hand, AWD may be applied by farmers who can avail of groundwater pumping in case of extreme drought. While the number of pumps and wells needed for groundwater access were rather limited in poverty-ridden rainfed areas, those facilities are more and more common throughout Asia [37]. The caveat of this proliferation of affordable pumping devices, however, is the encroaching scarcity of ground water by agricultural activities that increases pressure on fresh water resources [38,39].

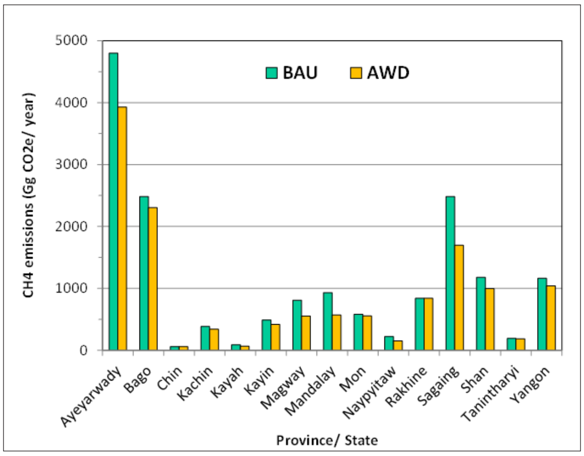

Figure 5: CH_4 emissions per division/ state for business-as-usual (BAU) rice production and AWD application in irrigated area

The AWD method was extensively tested and disseminated in irrigated rice in the Philippines, Vietnam, and Bangladesh that show large scale adoption [40]. This practice reduces water use about 30% without impacting yield if we implement properly [40]. AWD can also reduce CH4 emission [36]. Therefore, AWD was recognized as a promising mitigation option in a policy decree in Vietnam [41]. The practice has also been formalized as an approved methodology for mitigating GHG emissions under the Clean Development Mechanism (CDM) [42] as baseline scenario at national level, e.g. in the Philippines.

Figure 5 shows the annual CH4 emissions per subnational unit (irrigated and rainfed rice) of BAU juxtaposed by emissions of an AWD scenario. For this purpose, we have converted the emissions from CH_4 to CO_2e as a means to allow better comparison with the mitigation potential of other sectors as well as rice production in other countries. The latter assumes that this practice will be applied for the entire irrigated rice area of a given division/ state, but not in the rainfed area. The collective mitigation potential accounts for about 3000 Gg CO_2e/ year at national scale corresponding to 18% reduction against the baseline. This fairly low percentage reflects the low proportion of irrigated rice area. Broken up by sub-national units, the highest mitigation potentials were calculated for Ayeyarwady (837 Gg CO_2e/ year) and Sagaing (767). While Mandalay (361 Gg CO_2e/ year), Magway (256) and Bago (179) have moderately high mitigation potentials, the other sub-national units have only marginal potentials of less than 100 Gg CO2e/ year.

The role of rice for mitigation has been mentioned in the country's "intended" NDC of 2015 [43], but not in the "updated" NDC of 2021 [10]. Looking beyond the geographic focus of this study on Myanmar, however, the approach of reducing GHG emissions through water-saving practices is gaining more and more traction. The American Carbon Registry agreed "Voluntary Emission Reductions in Rice Management Systems" in which carbon credits will give farmers to implement the various practices like AWD [44]. In China, the common water management practice of 'mid-season drainage' is similar to AWD [45]. In 2009, the Philippine Department of Agriculture (DA) distributed an administrative order (AO 25) on 'Guidelines for the adoption of water saving technologies in irrigated rice production systems in the Philippines' which was not strict rule for AWD and termed as 'controlled irrigation' [46]. The Thai Rice NAMA project acquired funds from the NAMA Support Facility to reach out to 100,000 rice farms in Central Thailand in shifting from conventional to low-emission farming based on AWD in combination with Land Laser Levelling.

Conclusion

The improved data sets on spatial and seasonal distribution of GHG emissions alongside with their mitigation potentials derived from this study should assist in future mitigation policies in Myanmar. As such, improving the spatial and temporal resolution of GHG calculations will become instrumental to developing mitigation projects as done in other countries, e.g. in the Thai Rice NAMA project that specifically targets the irrigated areas in Central Thailand. At this point, the country still faces severe limitations to Greenhouse Gas (GHG) mitigation due to insufficient legal and economic instruments, technical capacity and funding. The Myanmar policy makers should try to adopt and accept the efficient use of water or sustainable use of natural resource such as water that can also increase yield and reduce GHG emission. Then they should set up the policy of this technology as the combination of one of the technical measures for rice grower to improve irrigation system. For the Myanmar biannual report of nationally determined contribution, the GHG result from this SECTOR tool can be used for GHG quantification of rice production.

This study can also be used to extract some take-home messages on the international efforts to compile a reliable and consistent inventory of GHG emissions in different countries, e.g. through FAOSTAT and EDGAR. In the case of rice production, the IPCC guidelines demand for a disaggregation of irrigated, rainfed and deepwater rice which represents a major caveat in achieving compatible data from different countries. While this distinction per rice ecosystem is not available in international statistics, the national statistics typically provide figures, but those are marked by idiosyncracies in the definitions by different countries. As long as Tier 2 Emissions Factors are not available, these national databases have to be combined with global defaults that are based on distinct perceptions of these ecosystems. Obviously, the resulting uncertainties will be especially pronounced in countries with high proportion of rainfed rice such as Myanmar as well as Thailand, Laos and Cambodia. Ideally, this problem can be overcome through GHG measurement campaigns that are conducted through national agencies responsible for doing the calculations in the NCs.

Finally, our study also pointed at another commonality of those countries with a proportion of rainfed rice, namely that the mitigation potential will inherently be lower as compared to countries dominated by irrigated rice. Up to now, only AWD has a documented track record to reduce GHG emissions at scale, but this practice has been developed for irrigated and not rainfed rice. As for the future, however, this should not exclude the development of mitigation options targeted to rainfed rice, e.g. adjusted protocols and infra-structure for capturing and releasing water without conversion to a fully irrigated system. By the same token, other options such as improved straw management could offer additional improvements in the overall cropping system of rainfed rice. The low baseline of GHG emissions in rainfed systems represents a very good starting point to achieve 'low-carbon' rice products in future markets with more environmentally conscious consumers.

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