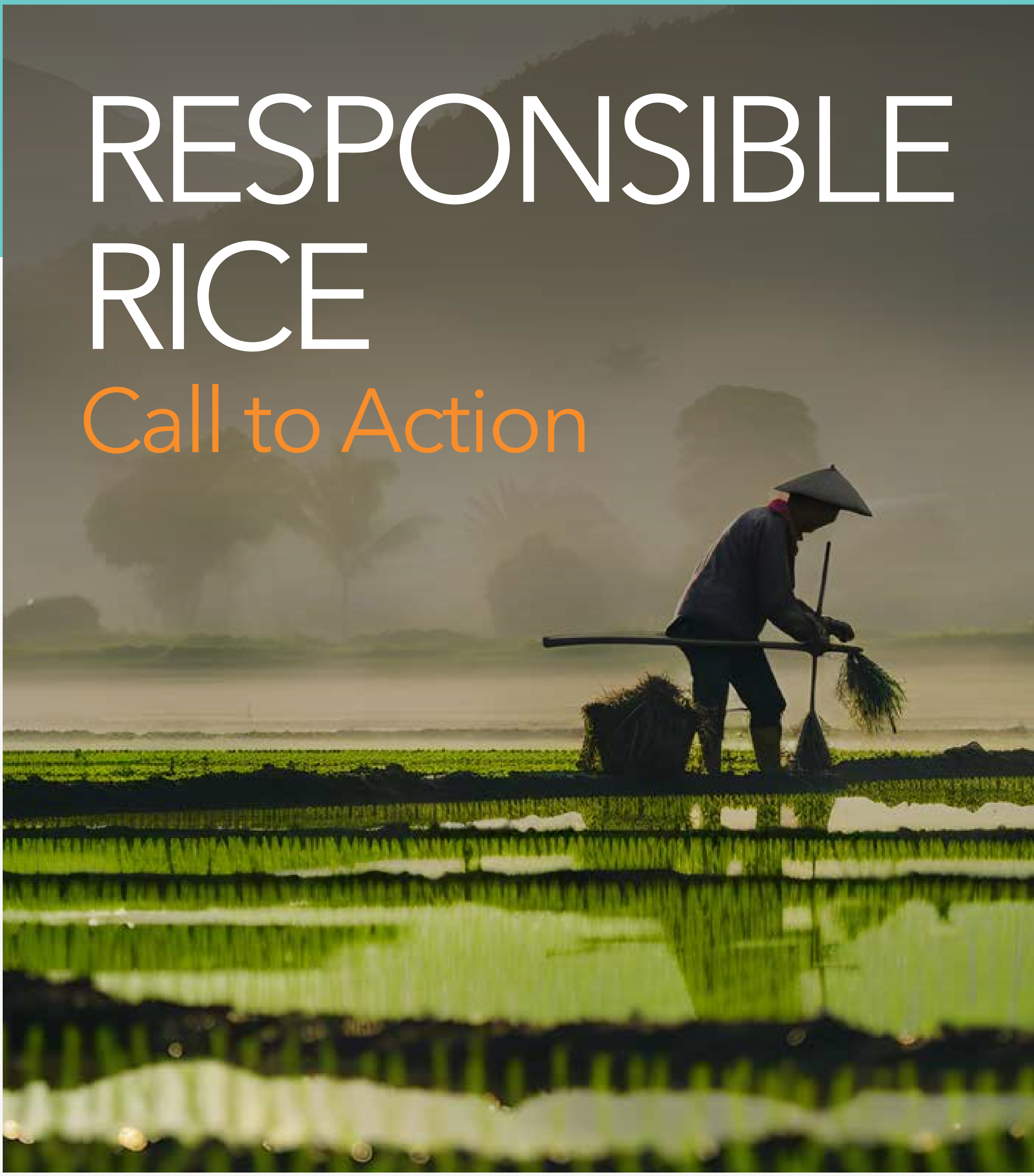
Whitepaper
2024

RESPONSIBLE RICE
Call to Action



SMART SCIENCE. CLEAN WORLD

String®

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Executive Summary

Rice holds a prominent position on the global food plate, constituting nearly 16% of the world's calorie intake. Most of its production is concentrated in Asia, where the top 10 producing countries contribute 84% of the total rice production worldwide. Therefore, rice has immense cultural, social, and economic importance in Asia, acting as a crucial commodity that influences economic growth and political stability. Ensuring an adequate, affordable, and stable supply of rice is crucial for the region. Over the last few decades, rice consumption has significantly increased worldwide, reaching from 157 million tonnes in 1960 to 520 million tonnes in 2022. Due to population growth in Asia, Africa, and Latin America, rice demand is expected to further increase by 30% by 2050, making it an essential component in the global food security equations. However, recent cultivation trends indicate a stagnation in crop yields and a shortage of land area for further expansion of rice fields. The rise in global temperatures is expected to lead to a 5-10% decrease in crop yields for every degree Celsius increase, posing further challenges in maintaining sustained rice production. Paradoxically, rice fields also contribute to climate change by emitting two potent greenhouse gases (GHG), methane (CH_4) and nitrous oxide (N_2O). Accounting for nearly 10% of global CH_4 emissions, continued rice cultivation worsens the very threat it faces. Therefore, innovative approaches are required to make rice ecosystems more resilient and productive while reducing the GHG emissions from the value chain.

Fortunately, various sustainable approaches are available today, ranging from seed-based interventions to practice-based interventions such as Alternate Wetting and Drying (AWD), Direct Seeded Rice (DSR), and innovative Crop Input solutions that primarily aim to reduce the CH_4 emissions from the crop. However, these interventions need to be scalable, easy to adopt by the farmers and create benefits across the value chain for effective societal implementation. CleanRise™ is one such biostimulant that prioritizes both climate impact and stakeholder value creation. It reduces CH_4 emissions upto 50% and N_2O emissions upto 40% while increasing yield upto 39% and providing added benefits downstream in the rice value chain. Scaling up such solutions is a crucial strategy for decarbonizing the agri-food sector.

Time is of the essence. With only seven years left to achieve the 1.5°C climate goal, urgent action is a priority. CH_4, responsible for 30% of global temperature rise since the Industrial Revolution, demands immediate attention. CH_4 is a short-lived climate pollutant with 86 times the global warming potential of CO_2. Therefore, focusing on its reduction in the near term allows us to manage the 1.5°C climate trajectory in the long term.

The rice sector is a notable contributor to our CH_4 abatement objectives given its emission contribution and high abatement potential. Fortunately, there are innovative and scalable solutions available in the agricultural sector like CleanRise, AWD, DSR and others which can unlock this potential. Given the technological maturity and commercial viability of existing solutions, realizing value not only at scale but also with speed becomes a key lever to reach our targeted outcomes. For instance, CleanRise can give an outsized impact if adopted widely and quickly ahead of 2035 timelines.

The rice ecosystem requires a systemic transformation that incentivizes sustainable rice production at all levels in the value chain. This transformation cannot happen by technology alone. An approach that also focuses on accelerating the adoption of new technologies is crucial to achieve our net zero ambitions. Realizing this vision of sustainable rice demands concerted efforts across farm fields, industry, academia, financial and policy spheres. The Responsible Rice Program is a strategic framework for driving systemic change in the rice value chain by uniting the stakeholders in the value chain and key external influencers like governments, academia, development banks and multilateral organizations. Responsible Rice refers to rice cultivated using practices that minimize GHG emissions, ensuring abundant, high-quality rice while enhancing farmer's well-being and prosperity. By aligning commitments across the stakeholders and building a focused approach to scale the right technologies, the program would aim to accelerate the adoption of Responsible Rice, delivering tangible benefits to the farmers, environment, and society at large.

The time for action is now. String Bio invites stakeholders to participate in this change and leverage the opportunity to transform the rice ecosystem for improved food security, reduced climate impact, and shared prosperity for all.

Reduce global anthropogenic CH4 emissions by

30%

below 2020 levels by 2030 to cap temperature rise at 1.5°C

The FAO Roadmap published in COP28 declares a milestone to cut gross GHG emissions of agrifood systems by 25% by 2030.

1

Evolution of Rice

Rice, scientifically known as *Oryza sativa*, though not native to tropical climates, has become synonymous with regions characterized by wet and humid conditions. While there are multiple theories to the origin of rice, South Asia is widely regarded as a cradle of rice cultivation, where ancient farmers first harnessed the potential of this remarkable crop. One notion suggests that rice evolved from wild grasses cultivated in fertile valleys of Eastern Himalayas with abundant water resources. Over time, the domestication and selective breeding of these wild grasses led to the development of rice. Another theory posits that rice roots back to Southern India, from where it gradually migrated northward, eventually spreading across East Asian nations like China, Japan, Indonesia, and the Philippines—now leading producers on a global scale. Furthermore, historical accounts hint that Alexander the Great's 327 BC invasion of India introduced rice to Greece, potentially paving the way for its European propagation.

Over time, rice has swiftly assumed a central role in agriculture and economies, shaping the dietary culture of nations and the global populace. It stands as a critical crop ensuring food security and nutrition, with rice paddies currently occupying 160+ million hectares globally. The crop's journey from its origins in South Asia to becoming a staple food in countries worldwide highlights not only its adaptability but also its transformative impact on societies and economies.

2

Cultural & Economic Significance

Rice, celebrated in a myriad of dishes like India's aromatic biryani, Japan's expertly rolled Makizushi, or Mexico's delightful Arroz con pollo, holds a unique position in the global cuisine, and is universally cherished by people worldwide. Beyond being a culinary delight, rice also serves as a cultural cornerstone intricately woven into the social fabric and daily customs of diverse East and Southeast Asian nations.

Rooted in religious beliefs, rice embodies sacredness in rituals, symbolizing health, prosperity, and spiritual blessings. In India, rice is an essential offering in religious ceremonies, fostering community bonds and collaboration. Festivals like Pongal, Baisakhi, and Onam mark the joy of rice harvests, expressing gratitude and abundance. In China, rice is integral to agricultural practices and folklore, with the planting and harvesting rituals celebrated during Dragon Boat and Mid-Autumn Festivals. In many African cultures, rice is an essential ingredient in traditional dishes that are served during weddings and other celebrations.

Rice production serves as a crucial source of livelihood for approximately 140 million rice-farming households and millions of rural individuals engaged as hired labor on rice farms across Asia. For impoverished consumers, rice constitutes a substantial portion of their daily food intake and nearly one-fifth of their total household expenditure, on average. The affordability of rice directly contributes to the alleviation of poverty for these vulnerable populations. Moreover, rice has evolved into a linchpin within the agricultural economies of numerous Asia-Pacific nations, wielding considerable influence over their gross domestic product (GDP).

The rice sector has also acted as a catalyst for rural infrastructure development in India, driving investments in irrigation systems, rural road networks, market connectivity, and storage facilities. This comprehensive approach not only fosters the growth of the rice industry but also simultaneously nurtures rural progress. Rice, being a strategic commodity, plays a key role in propelling overall economic growth and ensuring political stability in the region. Its significance is contingent upon securing an adequate, inexpensive, and stable supply of this essential crop.

Rice cultivation contributes to approximately

10%

of India's overall GDP.

3

Sustaining Food Security: The Rice Conundrum in an Era of Climate Change

3.1
Growing Appetite for Rice

Rice constitutes a significant portion of the world's food plate, accounting for nearly 16% of the calorie intake of the global population. It serves as a staple food for more than 3.5 billion people worldwide, with a predominant presence in Asia, Latin America, and parts of Africa. According to a study published in the journal Nature Food, the growing populations in Asia and Africa, expected to reach 5.3 billion and 2.5 billion, respectively, by 2050 (up from 4.7 billion and 1.4 billion today), will fuel a 30% increase in rice demand.

Over 90% of the world's rice is both produced and consumed in the Asia-Pacific region. Key contributors to rice production include China, India, Bangladesh, Indonesia, and Vietnam, collectively contributing to approximately 757 million tonnes in 2020. Global consumption has exhibited a substantial rise as well, increasing four times from 1960 to 2022, with an anticipated additional growth of approximately 6% by 2030.

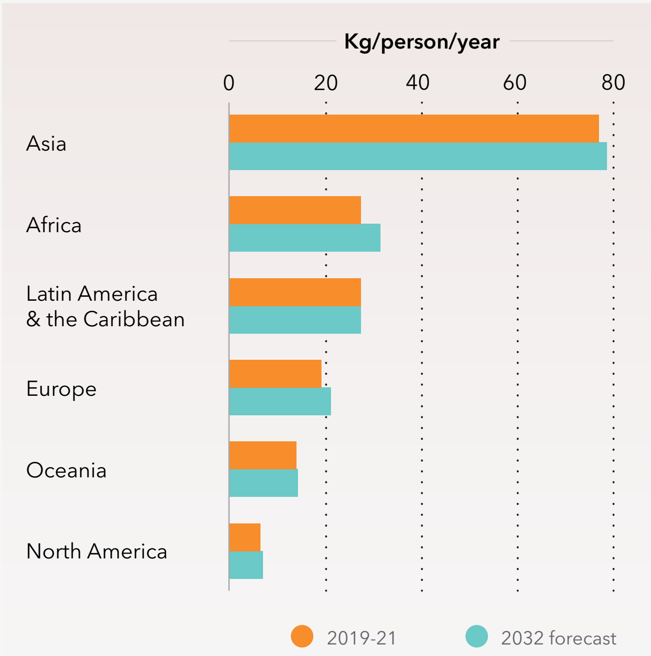


Figure 1: Average annual consumption of Rice per person by continents

Source: FAOSTAT 2022

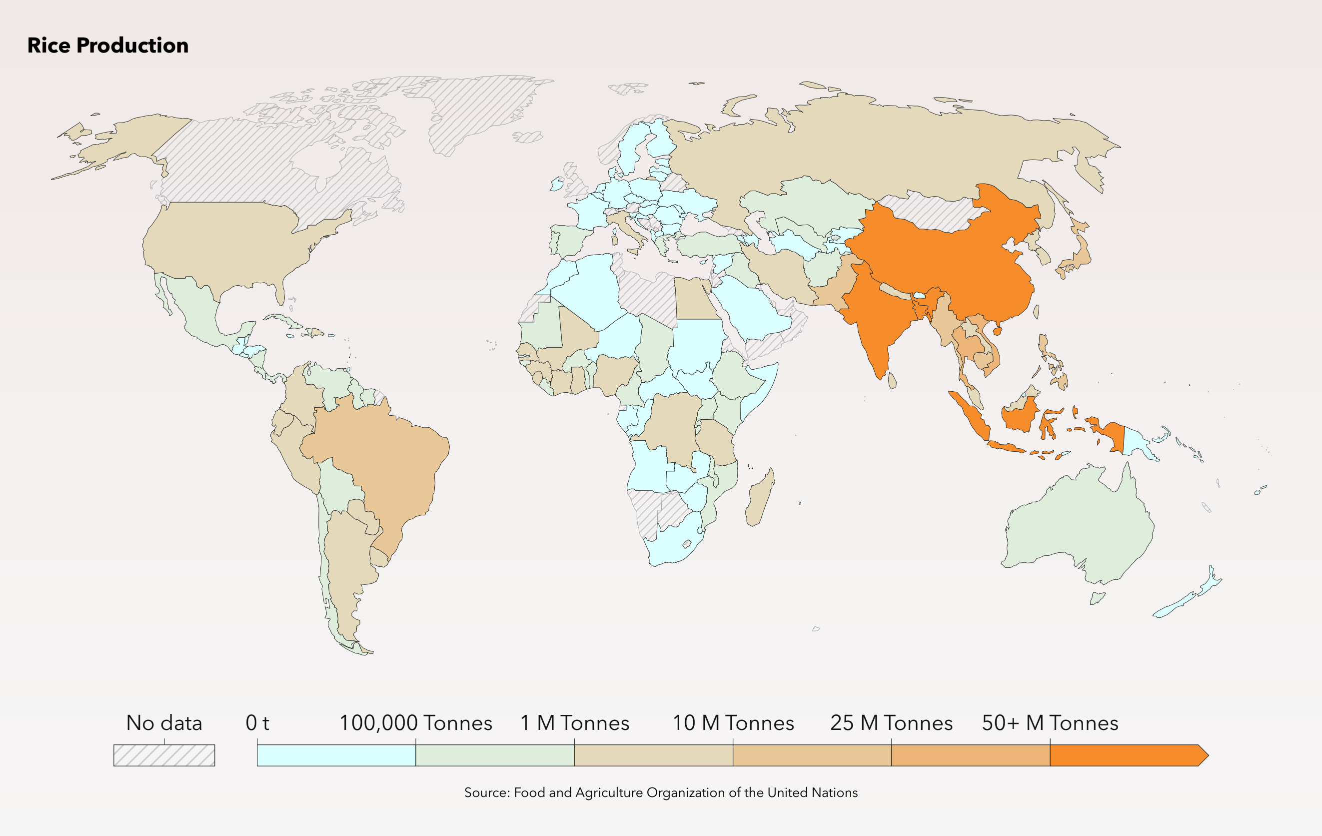


Figure 2: A global outlook of rice production indicated country wise (in M Tonnes)

Source: FAOSTAT 2022

Country	Production (M Tonnes)	Area Harvested (M Ha)
India	196	46
China	210	29
Bangladesh	57	11
Thailand	34	11
Indonesia	54	10
Vietnam	42	7

Figure 3: Production volume and area under rice cultivation in key Asian countries as of 2022

Source: FAOSTAT 2022

90%

of the world's rice is produced and consumed in the Asia-Pacific region.

3.2
Plateauing Rice Yields and Productivity

Rice cultivation is poised to directly impact global food security in the years ahead. Over a 45-year span from 1950 to 1995, rice production in the Asia-Pacific region adeptly met the demand by increasing yields, rather than expanding cultivation areas. However, in more recent times, yields have plateaued, and there has been no significant growth in the land area dedicated to rice cultivation in Asia over the last few decades, as illustrated in Figure 4 and Figure 5.

The future expansion of rice cultivation areas no longer presents a viable option for most Asian rice growing nations. Available land is becoming scarce, and the encroachment of urbanization and non-agricultural uses upon existing rice fields is occurring at an alarming rate. While there may be opportunities for land expansion in regions that lagged during the Green Revolution, the widespread adoption of high-yielding varieties and overuse of fertilizers has already taken place. We need to explore new methods to increase crop productivity without jeopardizing soil and environmental health.

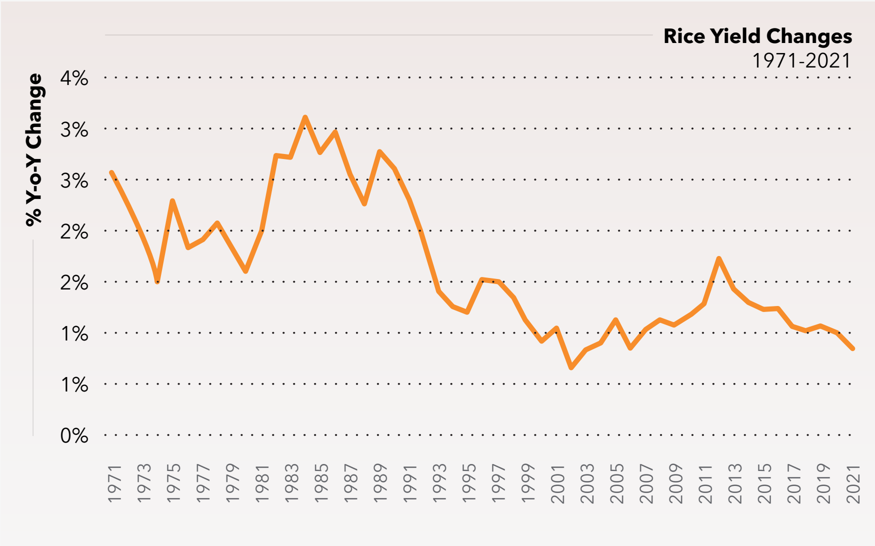


Figure 4: Decadal rice yield improvements (% Y-o-Y)

Source: FAOSTAT 2022

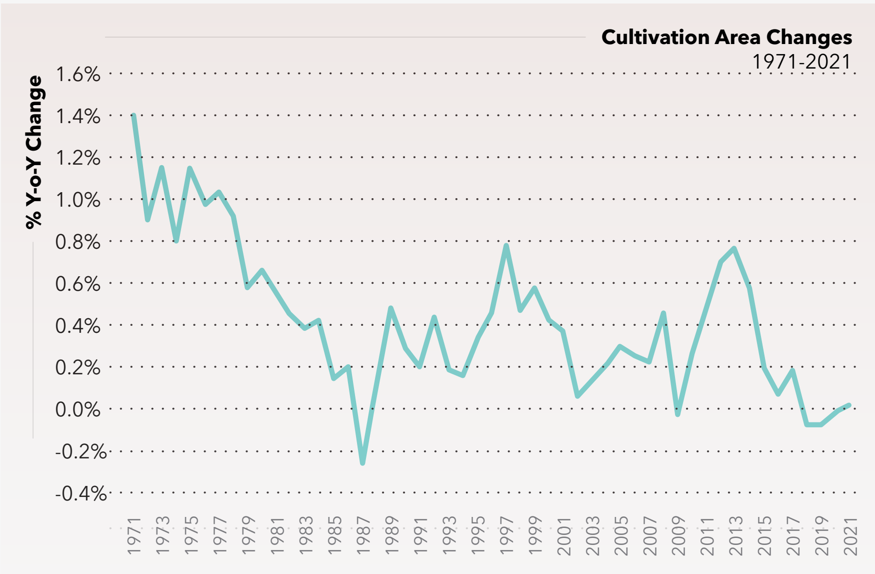


Figure 5: Decadal change in rice cultivation area (% Y-o-Y)

Source: FAOSTAT 2022

3.3

Unpacking the Climate Change

Rising temperatures are emblematic of climate change's impact, disrupting agricultural ecosystems and productivity. Elevated temperatures beyond the plant's optimum lead to a decrease in the photosynthetic rate and reduces biomass yields. Projections by the Intergovernmental Panel on Climate Change (IPCC) indicate that for every degree Celsius increase in global temperature, staple cereal crop yields are expected to decrease by approximately 5-10%. Apart from affecting crop yields, climatic parameters also influence nutrient and contaminant behaviour in soils, potentially altering their uptake into crops.

Globally, rice growers are contending with profound challenges in rice production brought about by climate change, primarily manifesting in alterations to rainfall patterns and the inexorable rise in global temperatures. In 2023, the global rice market registered its most significant shortfall in two decades, driven predominantly by climatic challenges in countries such as China, India, and Pakistan. For instance, Pakistan saw a staggering 31% decline in production due to severe flooding. China is currently grappling with the highest level of drought in its rice-growing regions in over two decades. In the Philippines, rice importation exceeded 3.8 million metric tons in 2023, the highest globally, as domestic supply struggled to keep up with escalating demand. As yields continue to decline due to both plateauing crop productivity and adverse climatic factors, it poses a considerable threat to the trade and economic balances between nations.

For every degree Celsius increase in global temperature, cereal crop yields are expected to decrease by

5-10%

4

Rice Farming's Environmental Quandary: Key Contributor to GHG Emissions

Rice is not merely a victim of climate change; it is also a major cause of it. Unfortunately, rice fields stand as significant contributors to global emissions of two potent GHGs: CH4 (CH4) and Nitrous Oxide (N2O). Rice cultivation contributes ~10% of total global CH4 emissions, that is comparable to the emissions from oil or gas sector (Figure 6(b). The largest rice cultivation areas are found in China, India, and Indonesia, making them the largest contributors to total CH4 emissions (Figure 7).

% share of global GHGs from human activities

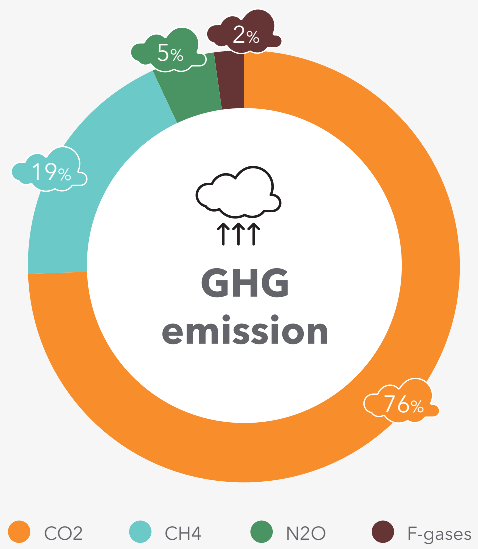


Figure 6(a): Global net GHG emissions from human activities (anthropogenic emissions) (GtCO2e yr–1), 2019

Global net anthropogenic GHG emissions include CO2 from fossil fuel combustion and industrial processes (CO2-FFI); net CO2 from land use, land-use change and forestry (CO2-LULUCF)9; CH4; N2O and Xfluorinated gases (HFCs, PFCs, SF6, NF3)

*GtCO2e converted based on GWP100-AR6

Source: IPCC, AR6 2022

% share of global CH4 emissions from human activites

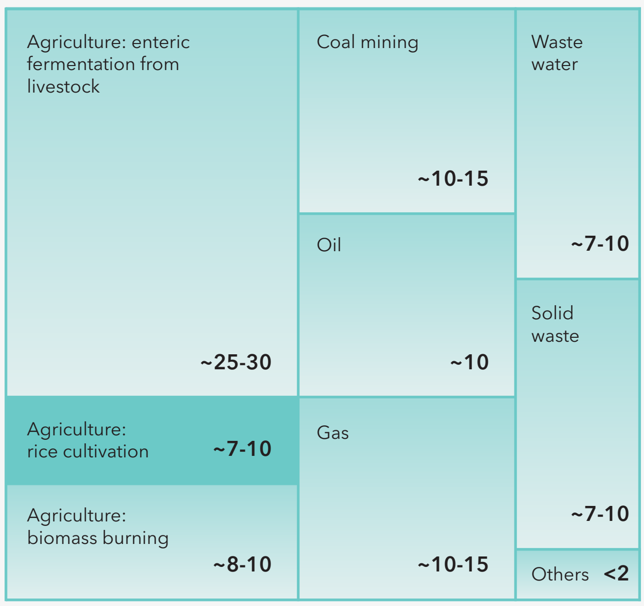


Figure 6(b): Global CH4 emissions from human activities are emitted by 5 key industries : Agriculture, Oil and Gas, Coal, Solid Waste and Wastewater

Source: Mckinsey & Company, Report: Curbing CH4 Emissions 2021

CH4, a hydrocarbon and a primary component of natural gas, wields a profound impact on the Earth's temperature and climate systems as a potent GHG gas. Ranking as the second most abundant anthropogenic GHG, following CO2, GH4's global warming potential is a staggering ~86 times higher than that of carbon dioxide over a 20-year period, underscoring its significant climate impact in the atmosphere.

Adding to this, N2O, the third most critical GHG, poses a substantial threat to our planet's well-being. The extensive use of nitrogen-based fertilizers in large-scale rice farming has resulted in a rapid surge in nitrous oxide emissions, indicating an increase of over ~30% in the last four decades. Similar to CH4, N2O exhibits higher potency than carbon dioxide; one pound of the gas is ~280 times more effective at warming the planet over a 20-year period.

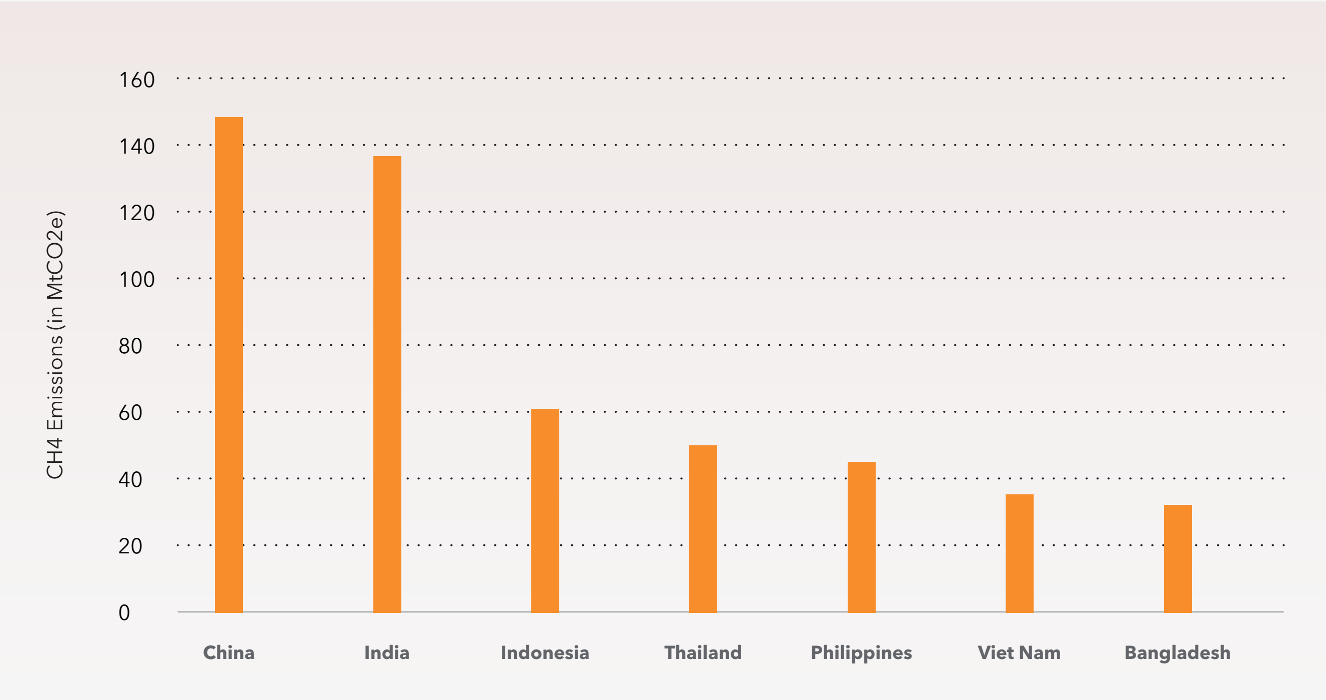


Figure 7: Top 8 countries in CH4 emissions volume from rice cultivation (MtCO2e, GWP-100 AR5)
Source: FAOSTAT 2022

This dual emission challenge jeopardizes rice's role as a fundamental component of the global food supply, particularly in Asia, where millions depend on successful abundant rice harvest for their nutritional needs. While rice sustains populations and increasing its production is imperative from a food security lens, methods of rice cultivation from the previous generation will only exacerbate global warming. Thus, it becomes important to innovate on sustainable approaches to rice cultivation that can tackle these challenges of: a. increasing yields b. bolstering resilience to climate-related stressors and c. reducing GHG emissions.

To develop effective technological interventions and targeted strategies, it is important to understand the fundamentals of how the rice plant generates these emissions, what physiological and biological factors are involved in the process and why has it been a challenge to curb them with the current practices.

5

The Science of GHG Emissions from Rice

GHG emissions in rice are a result of the multiple factors, with microbial environment around the crop growing conditions being one of the major driving forces. Various microbial processes, influenced by factors such as plant root exudates, the presence of organic matter, nitrogen fertilizers, soil properties, and climatic conditions (including temperature and precipitation), collectively impact emissions throughout the entire growth cycle of rice paddies. The emissions flux throughout the growth season is variable, with emission peaks achieved at different stages of growth depending on the farming practice deployed.

On an average, the annual global CH4 and N2O emissions are reported to be 283 kg/ha and 1.7 kg/ha respectively.

CH4 Emissions

Rice is a unique cereal crop grown under continuous flooded soil conditions which creates an anoxic environment favouring generation and emission of CH4. These emissions from rice fields are predominantly influenced by microbes in the soil, water levels in the field, and organic matter in the form of straw and manure. Under anaerobic conditions, organic matter provides substrate for a group of bacteria called methanogens, becoming the primary source of CH4 emissions. In the same fields, another set of microbial processes occurs that act as the sink for CH4 emissions. Production generally outweighs consumption, resulting in a net increase in CH4 emissions. The CH4 generated is transferred to the atmosphere via three pathways: ebullition (bubble formation, ~9%), liquid-phase diffusion through paddy water (1%), and transport through the plant's aerenchyma system (~90%) (Figure 8).

N2O Emissions

Nitrogen fertilizer application rate is the most important driver of N2O emissions from agriculture. Rice fields consume roughly one-seventh of total nitrogen (N) fertilizer resources and one-third of the irrigation resources utilized globally. Farmers apply large amounts of N fertilizer to maximize yield, but only upto 50% of N is taken up by the crop and the rest is lost from soil. This elevated usage contributes significantly to the formation of N2O. Microbial nitrification and denitrification processes affect N2O and Nitric Oxide (NO) emissions. Nitrification involves Ammonium (NH4+) oxidation to Nitrate (NO3-), releasing N2O as byproduct.

Denitrification reduces NO3− to Nitrogen (N2) under low oxygen conditions, releasing N2O as byproduct. Soil conditions including NH4+ and NO3- availability, moisture, temperature, along with the fertilizer application methods impact N2O emissions significantly (Figure 8). Under flooded condition, N2O escapes predominantly through the aerenchyma of the rice plants.

Crop management practices (rice cultivation systems) play a significant role in determining the GHG emission levels from rice fields.

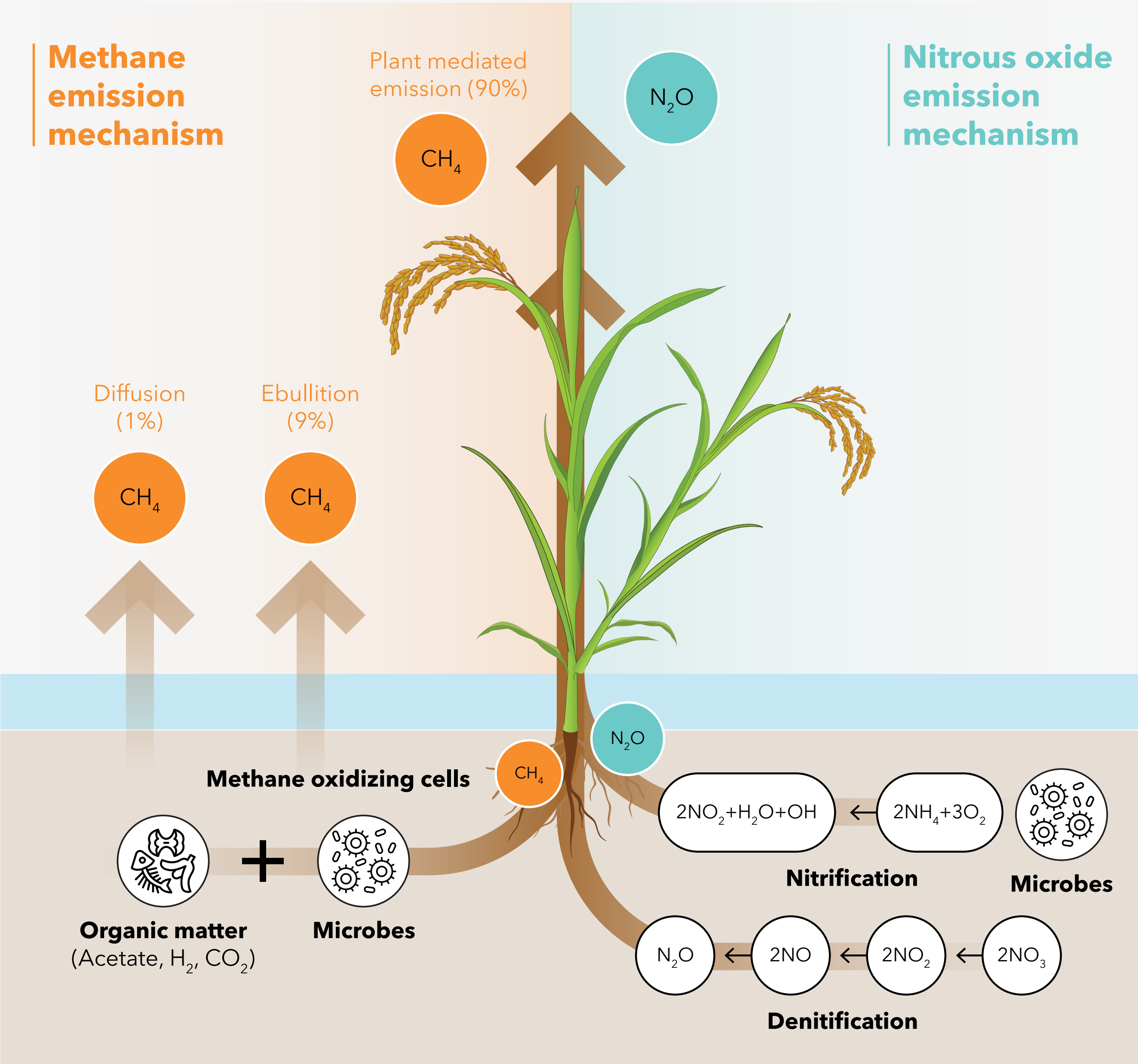


Figure 8: Representative diagram ellucidating mechanism of CH4 (left) and N2O (right) generation and emission from rice field environment.

Source: String Bio

6

Rice Cultivation Systems

The global landscape of rice production is characterized by diverse practices shaped by economic, cultural, and climatic factors across different nations engaged in rice cultivation. Classifications of rice environments are contingent upon altitude (upland, lowland, deep water), water source (irrigated or rainfed), and stand establishment technique (e.g., transplanting, direct-seeding, or water-seeding), yielding a multitude of combinations and variations. The chosen cultivation method significantly impacts key parameters related to GHG emissions from rice crop. The emission flux also varies across distinct stages of the rice growth cycle, encompassing tillering, flowering, grain filling, and maturity.

Flooded rice cultivation, despite its high-water demand and associated peak GHG emissions, remains the predominant system, with over 75% of global rice cultivators adopting this method. This preference is rooted in the substantial yield advantages it provides to farmers. Beyond enhanced yields, flooded rice cultivation offers ancillary benefits, such as an optimal growth environment that ensures consistent water supply, nutrient availability, soil fertility, nitrogen fixation, and the suppression of soil-borne plant diseases and weed growth.

The prevailing challenge in transitioning to sustainable rice production lies in the imperative to develop solutions that preserve the advantages in yield and robustness of deepwater rice cultivation while effectively mitigating the associated environmental consequences. Addressing this challenge necessitates the exploration and implementation of innovative approaches that balance the trade-offs between agricultural productivity and environmental impact.

~75%

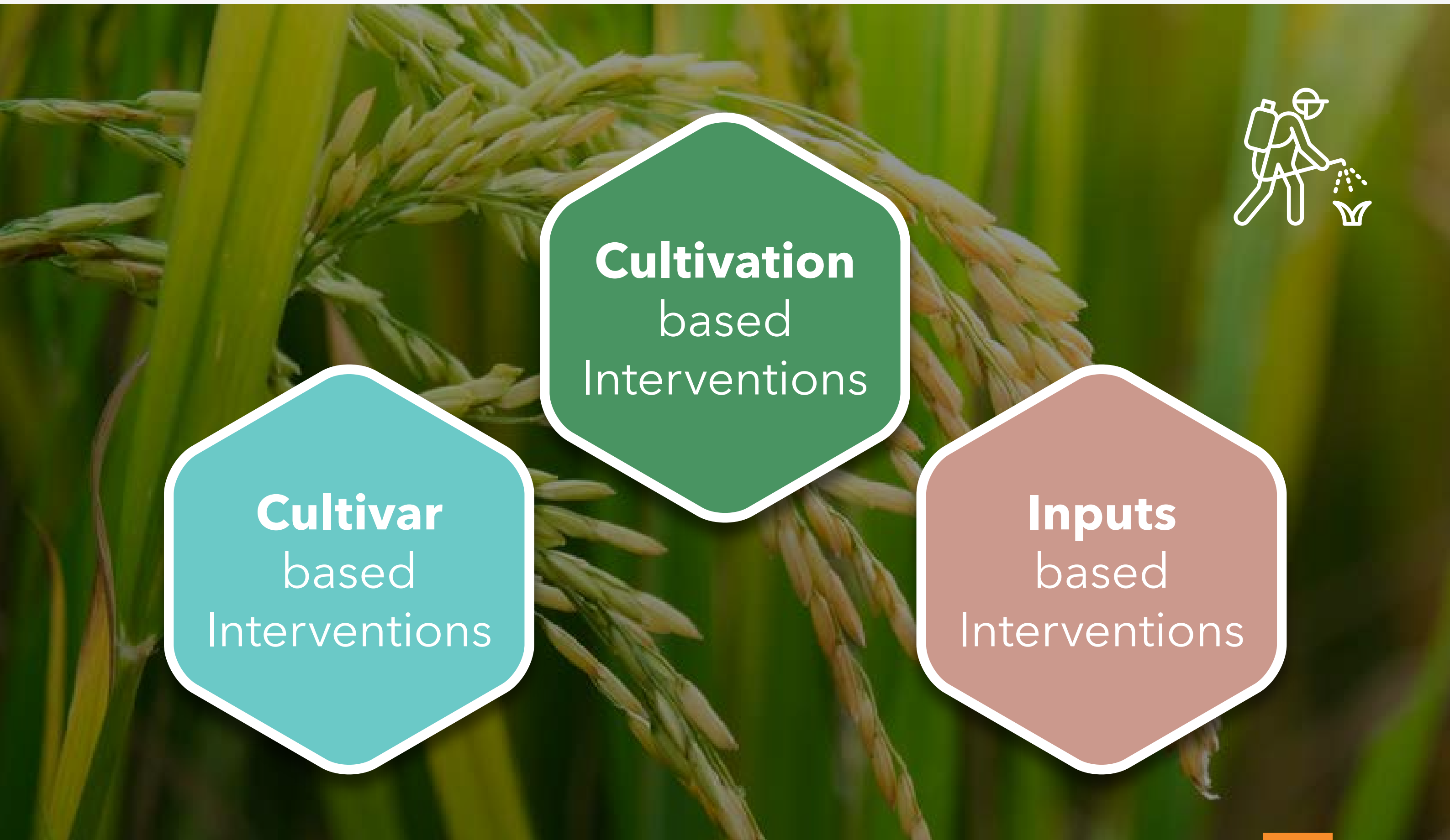
of global rice cultivation is under Flooded Rice.

7

Towards Sustainable Rice: Interventions for GHG Reduction

7.1
Systems Overview

Advancements in scientific research and innovations in agronomic practices have paved the way for various strategies aimed at mitigating the climate impact of rice production. These strategies coalesce under a comprehensive three-pronged intervention framework, encompassing cultivar-based, cultivation-based, and inputs-based approaches.



Cultivar based
Interventions

Cultivar Selection

Rice cultivars play a crucial role in influencing methane emissions from paddy fields. Serving as the primary source of organic matter and conduit for over 90% of methane fluxes, rice variety selection offers a promising mitigation strategy. Studies, such as Malyan et al. (2016), demonstrate that rice varieties with high root oxidative activity and low root exudation can significantly reduce methane emissions. However, widespread adoption of these varieties faces the challenge of geographical restrictions, with many cultivars limited to specific regions.

Genetically Modified Plants (GMO)

Researchers are developing low-emission rice varieties by modifying genes. For example, Su et al. (2015) overexpressed genes that divert nutrients to above-ground parts, while Iqbal et al. (2023) modified nitrate transporters, both leading to reduced methane emissions in lab settings. Despite promising lab results and some field studies in China, translating these benefits to real farms remains inconsistent and requires further work.

Cultivation based
Interventions

Alternate Wetting and Drying (AWD)

This technique involves periodic drainage and re-flooding of the paddy field, reducing methane emissions due to aerobic conditions in the soil, causing methane oxidation by soil microbes, while reported to have a counter increase in N2O emission. For safe AWD practice that doesn't compromise yield (risk associated with soil moisture level), the farmer needs to maintain adequate water levels through precise irrigation management. However, this poses a barrier to adoption as proper farmer training and irrigation infrastructure are required with little incentives for the farmer.

Drip Irrigated Rice

Drip-irrigated rice is a method of controlled application of water directly to the root zone of rice plants that is reported to reduce methane and nitrous oxide by promoting better nutrient management. A key bottleneck is the high cost of operations for installing a large number of drip lines in rice fields, that are generally narrow-spaced. Regular maintenance of drip system may lead to additional input cost to the farmers without guarantee of yield advantages that vary based on environmental conditions.

Aerobic Rice

This method involves growing rice under non-flooded conditions using specialized aerobic rice cultivars. An example of an aerobic rice variety is Apo, developed by the International Rice Research Institute (IRRI) for drought-prone areas. While aerobic rice can reduce methane emissions, it leads to increased N2O emissions and reduced rice productivity due to a high risk of weed infestations.

Direct Seeded Rice (DSR)

DSR is a method of sowing rice seeds directly into the field by broadcasting or line sowing. Irrigation is provided for 7-10 days depending on rain, soil type, and crop growth. Though it shows a reduction in methane emissions (shortened flooding duration), poor germination and suboptimal plant population may lead to reduced yields along with an increased tendency for weed infestation.

Inputs based
Interventions

Biochar

Biochar, charcoal made from rice husks, promises to reduce GHG emissions from rice fields by altering soil microbial communities and enhancing methane oxidation. However, while it might capture carbon, its effectiveness in real-world settings remains unclear. Additionally, potential drawbacks include contamination from pollutants and metals, long-term soil pH changes, and limited data on actual emission reductions.

Methane-Reducing Biostimulants

CleanRise, a methane-derived biostimulant, applied as a foliar spray on the crop, has demonstrated decrease in methane and nitrous oxide emissions by up to 50% and 40%, respectively, alongside a substantial 15-39% increase in crop yield, demonstrated in farm scale conditions. A key challenge is the lack of awareness about the product among the farmers and government bodies.

While there is potential for sustainable impact, these strategies present distinctive challenges that prompt concerns about their adaptability and accountability for creating on-ground impact at scale. The subsequent table provides a summary of the impact potential of prevalent sustainable rice practices, benchmarked against flooded rice cultivation. It evaluates parameters that influence their potential for widespread societal implementation and their capacity to drive consequential progress in addressing the climate impact of rice cultivation.

Intervention Type		Seed	Process		Product	
		Cultivar/ GMO	AWD	DSR	Bio Char	CleanRise
Degree of Environmental Impact	CH4 Emission	Positive	Positive	Positive	Uncertain/Neutral	Positive
	N2O Emission	Uncertain/Neutral	Negative	Uncertain/Neutral	Uncertain/Neutral	Positive
Impact on Yield		Uncertain/Neutral	Negative	Uncertain/Neutral	Uncertain/Neutral	Positive
Impact on Grain Quality		Positive	Uncertain/Neutral	Uncertain/Neutral	Uncertain/Neutral	Positive
Ease of Adoption	Capital Required	Positive	Negative	Negative	Positive	Positive
	Degree of Change of Farmer Practice	Negative	Negative	Negative	Positive	Positive
	Real World Validation	Uncertain/Neutral	Positive	Positive	Negative	Positive
	Farmer Acceptance	Uncertain/Neutral	Uncertain/Neutral	Uncertain/Neutral	Negative	Positive
Commercial Availability		Negative	Positive	Positive	Uncertain/Neutral	Positive
Value created in the Supply Chain		Negative	Negative	Negative	Negative	Positive
Scalability		Positive	Uncertain/Neutral	Uncertain/Neutral	Uncertain/Neutral	Positive
Market Awareness		Negative	Positive	Positive	Negative	Uncertain/Neutral

Positive Impact   Uncertain/Neutral Impact   Negative Impact

Figure 9: A comprehensive overview of existing sustainable rice cultivation technologies and their social & environmental impact that determines effective societal adoption

7.2
Technology Adoption for Sustainable Impact

The rice sector's transformation demands widespread technology adoption, but obstacles like technology robustness, negative impacts on yield, unclear return on investment, lack of awareness, and inadequate communication of benefits hinder progress. Farmer resistance to change, influenced by additional training efforts and the absence of economic incentives, is also a common challenge. Additionally, varied infrastructural support for smallholder farmers across regions further impedes adoption rates.

To address these challenges effectively, balanced approach is needed, encompassing technology maturation, awareness creation, and the retention of farmer incentives. Recently, scientifically backed agricultural inputs are emerging as a promising solution, alleviating the burden of change from farmers and avoiding extensive infrastructure upgrades while ensuring continuous economic benefits in the agricultural value chain. These input products, with their potential for large-scale impact, play a vital role in emission reduction while maintaining food security.

CleanRise, a microbial biostimulant from String Bio, exemplifies this approach by introducing scientific rigor to rice that priortizes both climate impact and stakeholder value creation. The multifaceted value offered by CleanRise is illustrated in Figure 10.

With a minimal application requirement (grams per acre), an affordable price point, and a multitude of benefits, this innovative solution aligns with the global imperative for sustainable and accelerated climate action in rice cultivation. The value created by reducing GHG emissions in rice becomes particularly impactful when scaled up.

Furthermore, the carbon credits associated with such extensive carbon abatement form an additional pool of financial incentives, encouraging and sustaining the technology's adoption by key stakeholders, including farmers and branders.

Beyond the environmental gains, CleanRise also generates significant social and community impact. By incorporating CleanRise into their agricultural practices, farmers, including marginalized groups, can enhance their livelihoods, bolster the resilience of their crops, and reap long term benefits of sustainable agriculture. This inclusive approach simultaneously improves local economies, empowers communities, and fosters social equity.

This presents an opportunity to foster a sustainable and resilient rice ecosystem, where climate action aligns seamlessly with agricultural prosperity.

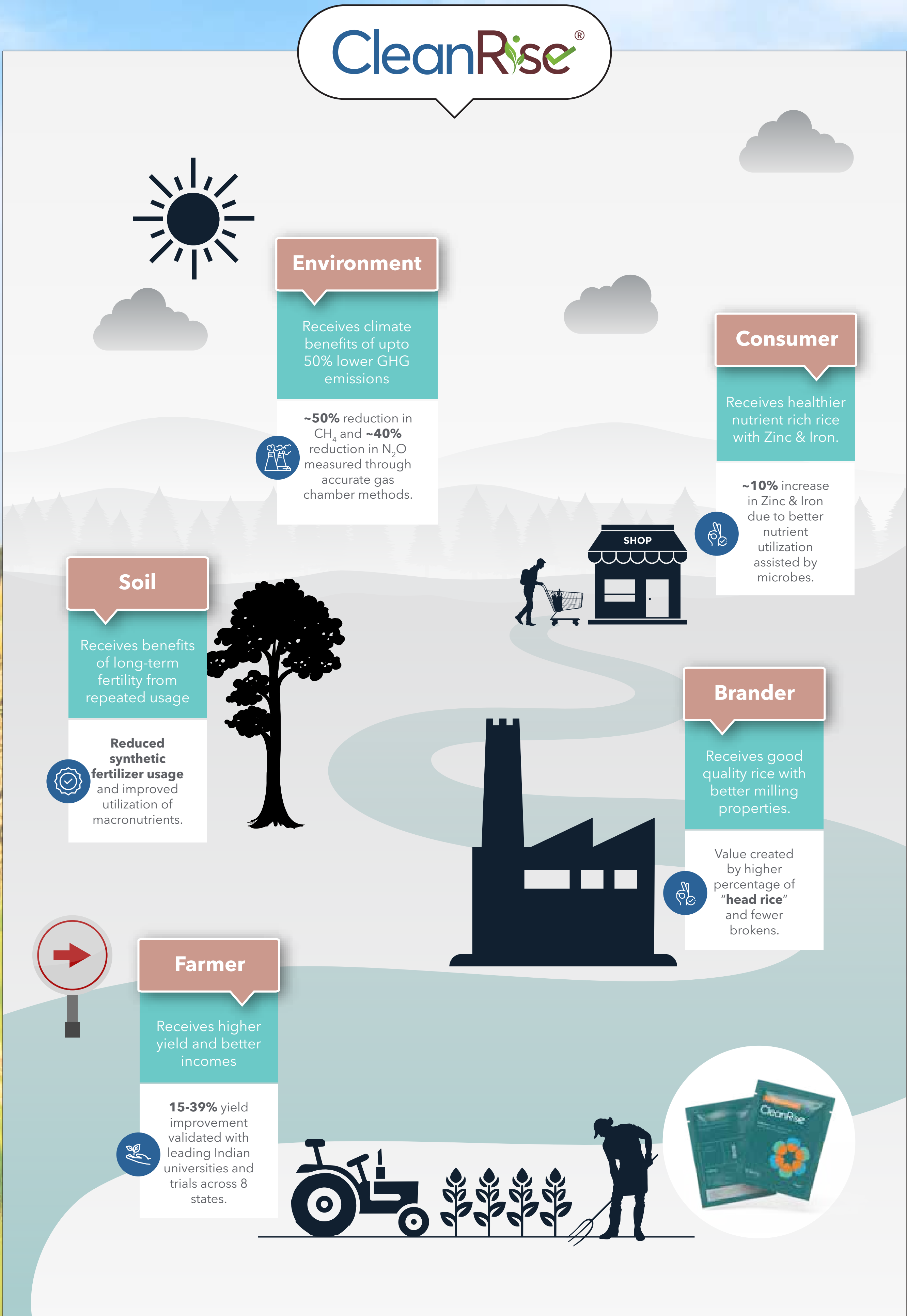


Figure 10: Value delivered across the value chain: Farmer → Soil → Environment → Brander → Consumer

An Urgent Call to Action

The 2015 Paris agreement set an ambitious goal to limit global warming to well below 2°C, ideally 1.5°C, by 2050. According to the IPCC's assessment, to achieve this we have a limited carbon budget of 570 GtCO2e. And at the current emissions level, we are likely to exhaust this budget by 2031. CH4 constitutes ~20% of global GHG emissions from human activities and is responsible for ~30% of the global temperature rise since the Industrial Revolution. It is a short-lived climate pollutant but exerts substantially higher influence on temperature rise. This means, if more CH4 gets emitted, carbon budget will exhaust quickly and the likelihood of capping the temperature at 1.5°C will significantly reduce. On the other hand, if CH4 is removed from the environment, it can reduce the pace of warming immediately/in the short term. Therefore, focusing on CH4 reduction in the near term is critical for managing 1.5°C climate trajectory in the long term.

Despite initiatives like Nationally Determined Contributions (NDCs), aimed at coordinating emissions reduction strategies at a national level, there remains a notable gap in CH4 abatement efforts. As elucidated in the Global Stocktake Report released during COP28, while approximately 80% of signatories incorporate CH4 into their broader GHG reduction targets, only a fraction (~15 countries) includes quantified CH4-specific objectives in their NDCs. This creates an implementation gap, termed the Emission Gap, when comparing projected 2030 GHG emissions based on NDC commitments versus actual projections derived from policy implementation in 2020 (Figure 12). Unfortunately, when viewed from the lens of rice cultivation, only five countries include dedicated rice related GHG targets in their NDCs, leaving significant mitigation potential untapped.

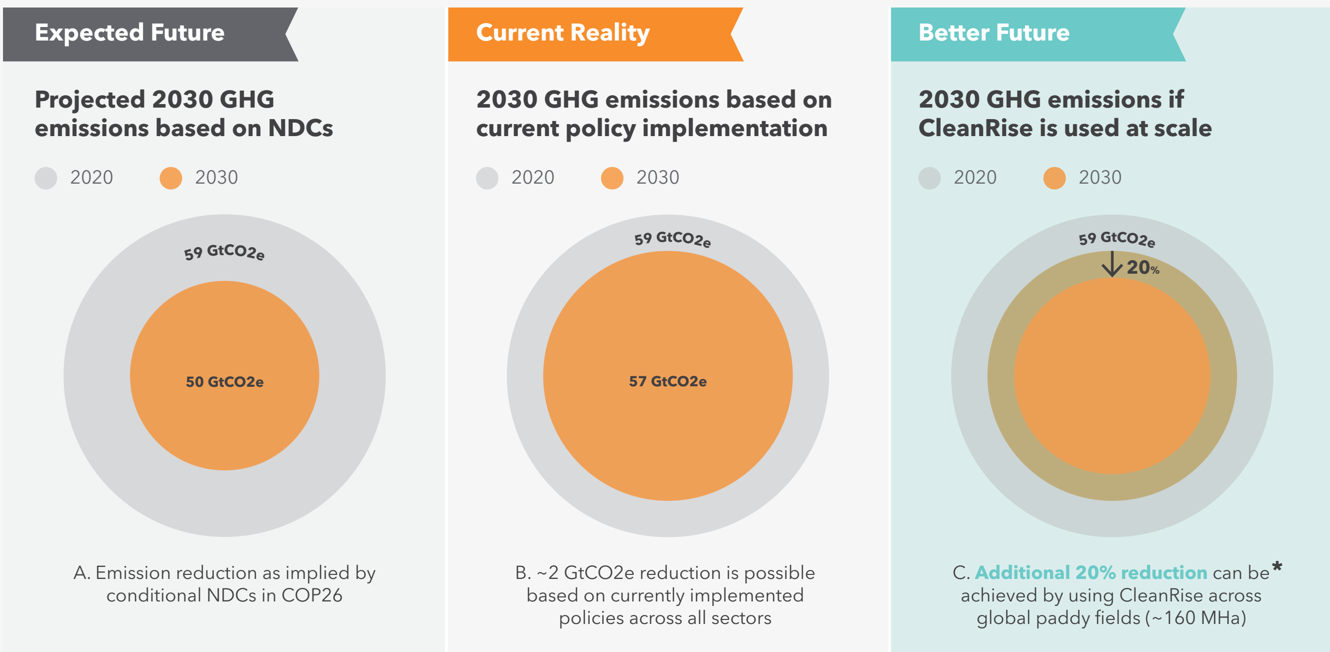


Figure 11: 2030 Emissions Gap: Projected 2030 global emissions based on NDCs vs emissions based on policies implemented by the end of 2020.

*The NDC Stocktake report facilitated comparison based on GWP-100 AR6 values. If we consider the more suitable GWP-20 factor as the conversion metric for CH4 emission, CleanRise impact would become 3X.

With only seven years remaining to bridge the emissions gap, the imperative for rapid emission reductions is indisputable. According to the Global CH4 Pledge, reducing CH4 emissions by 30% by 2030 from 2019 levels is necessary to uphold the 1.5°C pathway. Despite rice's significant contribution in global CH4 emissions, concerns about food security and farmer livelihoods have often relegated decarbonization efforts in the sector to the sidelines. Fortunately, innovative and scalable solutions in the agricultural sector, like CleanRise, AWD and DSR, seem well positioned to unlock rice's contribution to our climate objectives. Not only do such solutions have a significant impact on CH4 abatement in the agri-food sector, but they also address issues such as food security and farmer welfare. This presents an opportunity to tap into the abatement potential of sectors that have hitherto lacked global action.

Given their technological maturity and commercial viability, realizing value on scale becomes a key lever to get tangible outcomes and keep us on track for the 1.5°C climate goal. For example, CleanRise for rice cultivation can give outsized impact if adopted widely and quickly. By using CleanRise on ~40% of global rice fields (equivalent to approximately half of the rice fields in India and China), we can get upwards of 523 MtCO2e* of emissions reduction. Scaling up to cover 100% of global rice fields, CleanRise has the capacity to contribute a remarkable 13% (~1307 MtCO2e*) towards the Global CH4 Pledge target, all while maintaining food security.

As we approach the critical tipping point for achieving climate targets, it is important to consider the time value of carbon when working on technology implementation. A tonne of carbon avoided, reduced or removed today is more valuable than a tonne in the future. It becomes important to address barriers in fast adoption to maximize the value delivered by these solutions. For instance, CleanRise boasts advantages such as low capital costs and ease of adoption. Even with these benefits, with existing market adoption curves it might take us till 2062 to leverage it's full climatic benefits, a timeline that is far too delayed considering our urgency of climate impact. By solving financial, social, and regulatory challenges through a coordinated approach, it is possible to accelerate market adoption and unlock tangible emission reduction potential within the critical timelines of 2030 and 2050 (Figure 12).

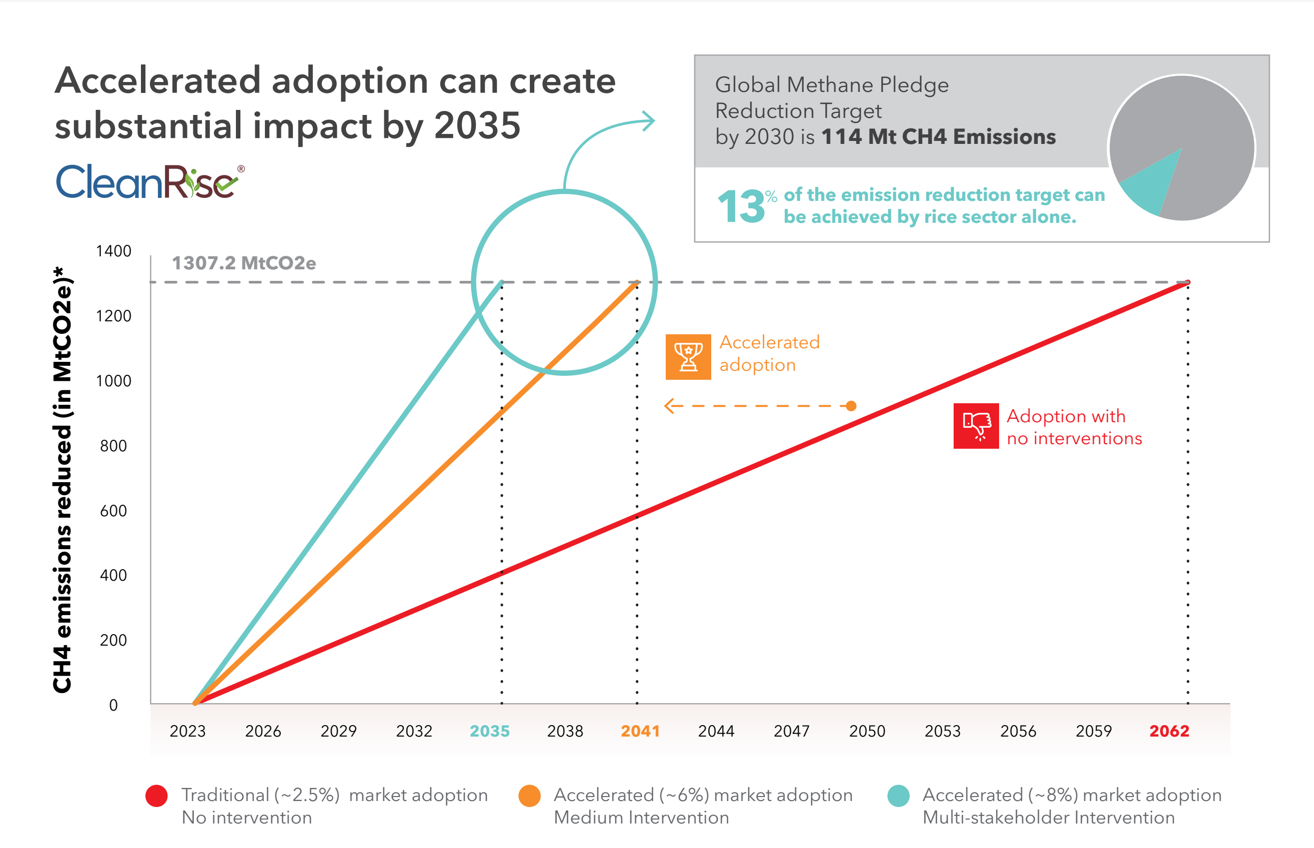


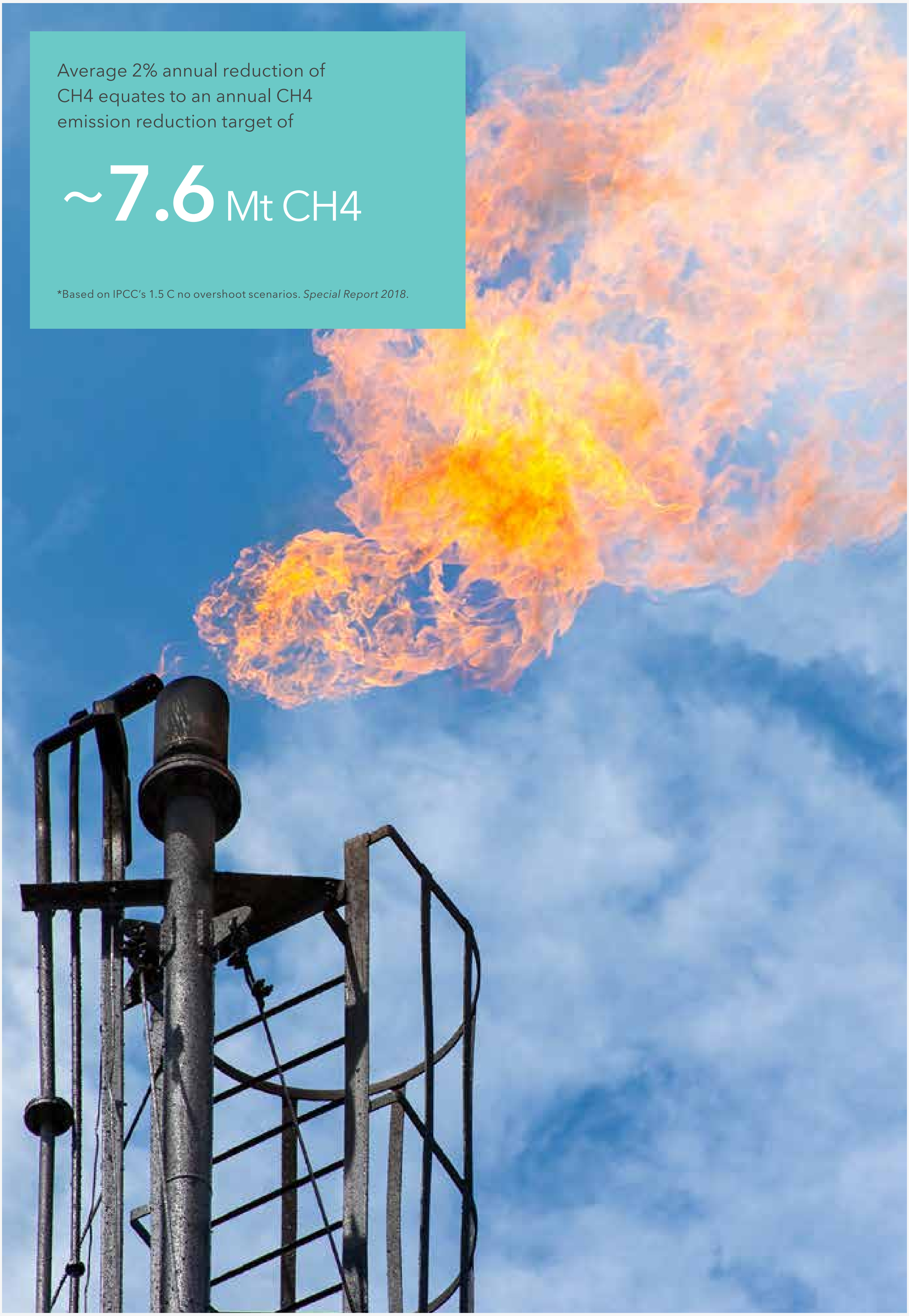
Figure 12: CleanRise market adoption scenarios. The graph illustrates different rates of CH4 emission reduction that can be achieved at different levels of market adoption.

*The emission reduction potential is calculated based on GWP-20 AR6. As highlighted in IPCC AR6 report, CH4 warming potential is more accurately represented in 20-year GWP when calculating impact over a few decades of time horizon.

Average 2% annual reduction of CH_4 equates to an annual CH_4 emission reduction target of

~7.6 Mt CH_4

*Based on IPCC's 1.5 C no overshoot scenarios. *Special Report 2018.*



9

Transforming the Rice Ecosystem: The Responsible Rice Program

As the urgency for action becomes increasingly evident, String Bio calls for a collective action plan aimed at achieving systemic impact in the rice value chain, under the overarching framework of "**Responsible Rice**". This concept entails all work, direct or indirect, to rapidly enable rice cultivation using practices that not only minimize GHG emissions but also enhance yields to ensure abundant availability of rice. The recent signing of the Food and Agriculture Declaration and the launch of the FAO Roadmap for Change during COP28 in Dubai have catalyzed fresh momentum in this space and spurred attention of stakeholders. The present moment provides a rallying point for stakeholders to unite efforts and drive changes at a systemic level in rice production.

Achieving this shift towards sustainable, low-carbon rice cultivation demands a commitment from all stakeholders in the rice ecosystem such as farmers, agricultural input providers, corporate branders, traders, processors, and consumers. While cost-effective solutions, like CleanRise, exist to bridge the 2030 emissions gap, there is missing support for scaling these solutions efficiently. Proactive engagement from external entities like multilateral organizations, financial institutions, government bodies, and knowledge institutions, would be essential in building the support system that propels change.

For an effective action plan, a strategic alignment of efforts is key. We need to work across the spectrum - raising awareness, implementing strategic sourcing practices, creating appropriate incentives, facilitating monitoring, and driving behavioral shifts at all levels in the value chain. String Bio proposes the **Responsible Rice Program** as a coordinated initiative to facilitate this transformation.

The Responsible Rice Program would aim to transform farmer practices, promoting a sustainable and environmentally responsible approach to rice cultivation, delivering value to farmers, while ensuring the equitable distribution of carbon abatement benefits. It also aims to push for country-driven cooperation to build and retain capacity at all levels for sustained climate action.

Figure 13 illustrates a potential action plan for how these stakeholders can work in alignment to accelerate the widespread adoption of Responsible Rice.

How can the stakeholders drive transition to Responsible Rice?

Farmers and Growers

At the core of rice value chain, key adopters of change.

- Embrace new technologies and sustainable cultivation practices.
- Commit to following protocols for producing Responsible Rice and cooperate for validation/certification.
- Aim to convert 100% of land area under rice cultivation practices by 2030.

Processors & Brands

Critical stakeholders who can "pull" the change in the value chain.

- Commit to sourcing Responsible Rice to create market demand. For E.g. 25% by 2025, 50% by 2030, 100% by 2035.
- Engage farmers in programs where package of practices is provided, and output offtake is guaranteed.
- Educate consumers on the importance of Responsible Rice and encourage them to choose responsible products.

Governments

Key stakeholder that can drive change at scale and influence NDCs.

- Provide incentives and formulate policies supporting farmers in adopting Responsible Rice practices aligned with NDCs.
- Utilize the extensive government network to educate farmers on best practices.
- Fund the off take of sustainable products and technology for widespread availability to farmers.

Multilateral Organizations

Shapers of global priorities and can support activity change in critical regions.

- Prioritize rice agenda under net-zero goals, work with governments to establish initiatives for Responsible Rice.
- Develop regional networks for sharing rice technology and market information.
- Establish exemplar projects in vulnerable areas to demonstrate impact created.

Commercial & Development Banks

Capital providers who can innovatively deploy the committed climate funds.

- Offer financial instruments rewarding carbon mitigation in rice cultivation for both farmers and corporates.
- Introduce favourable insurance products to incentivize growers following Responsible Rice practices.
- Provide favourable investment terms for organizations building capacity for Responsible Rice adoption.

Knowledge Institutions

Source of latest scientific advancements and technological innovations.

- Create awareness on technological innovations in farming practices and sustainable technologies.
- Develop the "best package of practices" and conduct capacity-building workshops for farmers.
- Leverage networks to steer awareness on new innovations and technologies among rice stakeholders.

Climate Action Groups

Create climate awareness and monitor progress on climate impact.

- Create awareness on climate impact of rice production.
- Advocate for commitments towards Responsible Rice adoption, emphasizing its significance in climate change.
- Educate consumers about the issues with current rice production and the need for Responsible Rice.

Figure 13: Suggestive actions for stakeholders under the Responsible Rice framework.

String Bio invites all stakeholders to join this transformative journey, fostering a future where Responsible Rice sustains farmers' livelihoods while mitigating the environmental impact of rice cultivation—a collective effort toward a greener and more responsible rice sector for generations to come.

About String Bio

String Bio, a leading biomanufacturing company based in India, is at the forefront of addressing food security and climate change through innovative solutions. We leverage advanced microbial fermentation technology to convert CH4, a potent GHG, into high-value ingredients for agriculture, animal feed, and human nutrition.

Our bio-based and climate-positive products have been tested and validated by leading universities, commercial partners and customers across the world. In the field, String Bio's commercialized bio-stimulants, including microbial and protein hydrolysates, demonstrably enhance crop yields and productivity while lowering carbon footprints.

Produced in our state-of-the-art plant in India and backed by the strong and consistent performance, String is now looking to introduce these carbon friendly products to growers globally. Committed to global impact, String Bio is open to collaborate with diverse stakeholders to create a sustainable and food-secure future.

For extended discussion on the Responsible Rice Program or interest in our product portfolio please reach out at **responsiblerice@stringbio.com**

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