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# Reducing the Need to Burn: How Applying Sustainable Agricultural Mechanization in South and Southeast Asia can Improve Air Quality



**CSAM**

Centre for Sustainable  
Agricultural Mechanization

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# I. INTRODUCTION

Exposure to air pollution is now considered the greatest environmental risk to human health, with around seven million global premature deaths attributed to it annually, including over 700,000 children[1]. In South and Southeast Asia, air pollution exposure is a serious problem, with around two billion people living in regions where fine particulate matter (PM<sub>2.5</sub>) pollution exceeds the WHO[2] guideline level[3-5]. Yearly average

PM<sub>2.5</sub> concentrations in South and Southeast Asian countries have remained persistently high, with concentrations in India, Nepal, and Bangladesh increasing in recent years (see Figure 1). Population-weighted PM<sub>2.5</sub> concentrations in 2020 ranged from around 2 to 15 times the WHO Air Quality Guideline, with the lowest concentration in Brunei and the highest in Bangladesh.

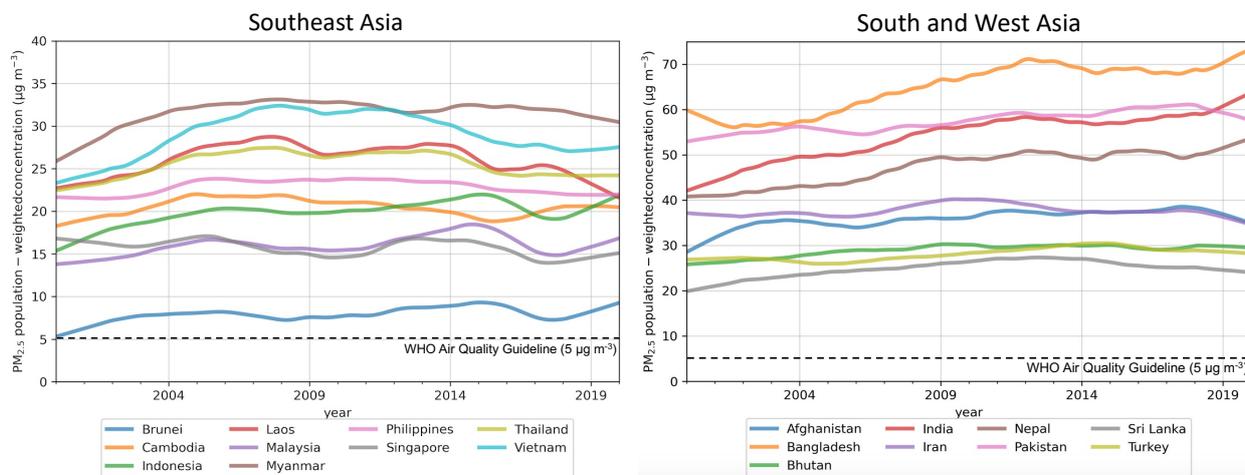


Figure 1. National population-weighted PM<sub>2.5</sub> concentrations for Southeast, West, and South Asian countries between the years 2000 to 2020. Note the different PM<sub>2.5</sub> concentration scales for the difference regions. Figures were produced using PM<sub>2.5</sub> data from van Donkelaar et al.[6] and population data from CIESIN[7].

Some of the largest sources of PM<sub>2.5</sub> exposure in South and Southeast Asia are open burning of agricultural residues, forest clearance fires, and peatland fires, particularly during burning seasons[7-12]. These fires are also responsible for substantial greenhouse gas (GHG) emissions[13-17]. Huge amounts of crop residues are burnt in these regions every year, more than in any other world region (see Figure 2). In 2020, the amount of biomass dry matter burnt per square kilometre of agricultural land in South and

Southeast Asia was over double that in North America and mainland China[18,19]. Exposure to PM<sub>2.5</sub> pollution from agricultural and forest fires is associated with adverse health outcomes including morbidity and mortality in Asian populations[20-24]. Preventing these fires in South and Southeast Asia could have a significant public health benefit by substantially reducing regional air pollution and subsequently avoiding hundreds of thousands of premature deaths yearly across the region[9-11].

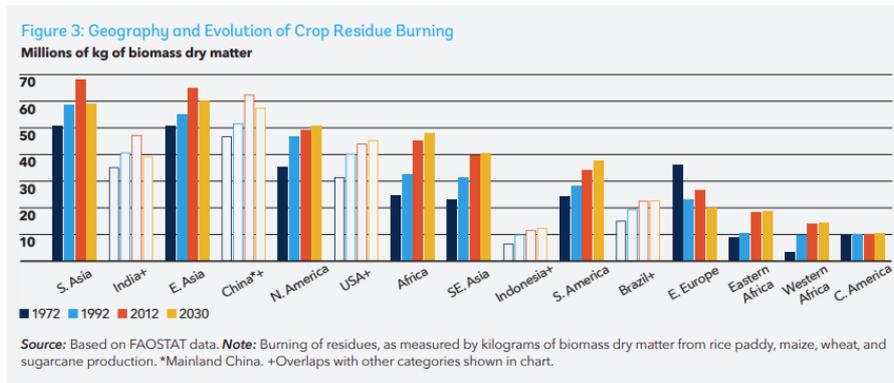


Figure 2. Geography and evolution of crop residue burning.

In addition to increasing GHG emissions and causing adverse effects on air quality and public health, agricultural residue burning can negatively affect soil health, leading to a loss of soil carbon and micro-nutrients, while adversely affecting soil temperature, pH, moisture, and organic matter[25]. Farmlands that have undergone repeated burning generally have reduced soil fertility[26] and higher erosion rates[27], requiring increased use of fertilizer[28]. However, viable no-burn alternatives exist that can provide both environmental and economic benefits to the farmers[29].

Implementation of modern agricultural machinery can promote the transition to sustainable and integrated management of agricultural residues, for example using machinery to compress and transport straw as bales for use as livestock feed/bedding, bioenergy, mushroom substrate, or industry material[30]. Machinery and equipment can also be used to support and enhance the conversion of straw residues to improved animal feed and fertilizer. After harvesting, using direct/zero-till seeder can further benefit the farmer; reducing the seed

amount and increasing the seed survivability, even if rainfall is limited, thus improving the resistance of the cropland to future climate change. Moreover, with direct seeding the crop matures and can be harvested earlier, allowing more time for the stubble to decompose before the next cropping cycle, thus discouraging burning.

Reducing air pollution from biomass burning in the agricultural sector in South and Southeast Asia will help countries uphold their commitment to the 2015 Paris Accords and other global conventions and standards to tackle climate change. In addition, agricultural emissions reductions would support the attainment of the targets laid out in the Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty) target 1.4 (poor have equal access to appropriate new technology), SDG 2 (Zero Hunger) target 2.4 (ensure sustainable food production systems, SDG 12 (Responsible Consumption and Production) target 12.2 (promote efficient use of natural resources), and SDG 13 (Climate Action) target 13.1 (strengthening adaptive capacity to climate-related hazards).

## II. PROJECT BACKGROUND

### A. The CSAM Regional Initiative on Integrated Straw Management

In 2018 the Centre for Sustainable Agricultural Mechanization (CSAM) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), with the support of ESCAP's Environment and Development Division, commenced a regional initiative to promote

mechanization-based solutions for integrated management of crop straw residue to enable sustainable and climate-smart agriculture. The main objective was to identify, test and adapt innovative agricultural equipment and machinery for alternate uses and sustainable management of straw residue which could reduce farmers' inclination to openly burn this potentially valuable resource, thereby reducing air pollution and GHG emissions from the agricultural sector and preserving soil health. The approach was centred

around a circular model (see Figure 3) of straw management within farming communities including use of straw for purposes such as

fertilizer, fodder, substrate for mushroom growing and production of clean energy.

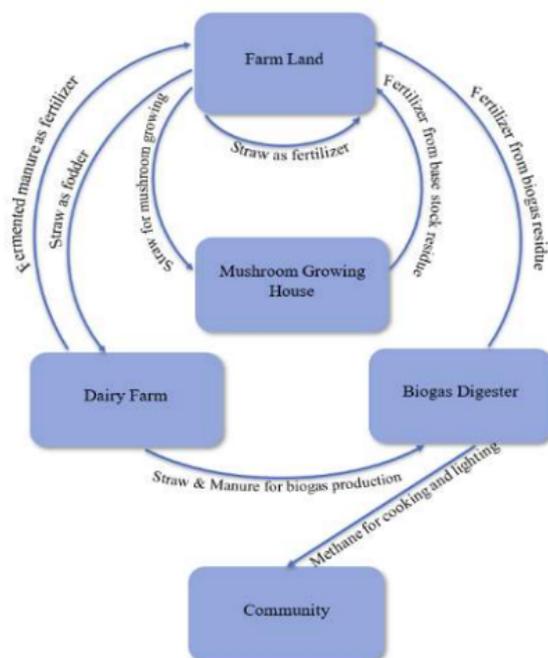


Figure 3. Circular model of straw utilisation.

Following the launch of the regional initiative, positive results were attained via pilot projects implemented in China and Viet Nam in collaboration with national partners, where agricultural machinery was applied and optimized to improve current practices and provide suitable alternatives to burning straw residue that enabled ecological and economic benefits for the farms involved. For instance, the pilot in China demonstrated utilisation of wheat and maize straw as fertilizer, fodder and production of biogas, in-place of burning, whilst increasing crop yields, soil organic matter, and the net income of the local farmers cooperative. The pilot project in Viet Nam demonstrated the yield and quality enhancement benefits from using straw to cultivate mushrooms via an indoor method. Moreover, India, which had already established a large-scale national project to combat straw burning, contributed to the initiative as a knowledge-sharing partner and hosted a study tour in 2019 to demonstrate related machinery and good practices.

In 2021 the regional initiative expanded further to build on lessons learned, with pilot sites in Cambodia, Indonesia, and Nepal. It engaged with the farming communities at pilot sites to first understand their needs through baseline assessments and workshops, then implemented

technical interventions by providing training and agricultural machinery/equipment to the local community and documenting the successes and learnings in the real world (see following section on the pilot projects).

The results of this work have shown how new measures can be applied effectively when directly engaging with local stakeholders to explore contextually suitable approaches and identify machinery that can be adapted to serve their needs.

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## B. Identifying key areas for interventions

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Pinpointing where to apply these interventions involves identifying the areas with greatest fire activity, typically requiring a robust system to monitor and measure burning hotspots and the associated air pollution. ESCAP has been undertaking work to help governments target where interventions are critically needed which has complemented the CSAM regional initiative. This work uses advanced data science practices to build a machine learning model that relies on simple data and the moderate-resolution imaging

spectroradiometer (MODIS) satellite images to identify hotspots and make more accurate predictions about policy impacts. This model has been tested across the Asia-Pacific region, along with an in-depth case study done hand-in-hand with the local government in Chiang Mai, Thailand. Combining this methodological approach with

techniques from the CSAM regional initiative can significantly reduce the impact of air pollution by informing farmers and decision-makers of burning hotspots where the need for mechanisation should be prioritized to be most relevant.

## III. PILOT PROJECTS ON INTEGRATED STRAW MANAGEMENT

Agreements for implementation of the pilot projects in Cambodia, Indonesia and Nepal were signed in 2021/2022 between ESCAP and the national partners, namely Swisscontact in Cambodia (in close collaboration with the

Department of Agricultural Engineering of Cambodia); Purwanchal Campus, Tribhuvan University in Nepal; and Universitas Gadjah Mada in Indonesia. The pilot projects aimed to deliver the following three outputs:

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- Output 1** Establish pilot site(s) in Cambodia, Indonesia, and Nepal for integrated management of straw residue informed by research on air pollution and GHG emissions from the agricultural sector.

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  - Output 2** Test and adapt improved technologies and practices for integrated management of straw residue at pilot site(s).

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  - Output 3** Enhance capacities of farming community and change agents for adopting improved technologies and practices for integrated management of straw residue.
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### A. Pilot sites

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The project established three main pilot sites for the implementation and testing of mechanisation-based solutions for integrated straw management: 1) Treang District, Takeo Province in Cambodia; 2) Morang District, Province 1 in Nepal; and 3) the Special Region of Yogyakarta in Indonesia. The pilot sites were generally characterized by paddy as among the main crops and often following the cropping-livestock system. Farmers tended to frequently burn the straw residue at the pilot sites for various reasons.

### B. Key activities of pilot projects

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During the first stages of the projects, the farming communities at the pilot sites were engaged

through workshops and baseline surveys, to understand the farmers' needs, the agricultural conditions of the farms, and the current straw management statuses. Next, new or improved agricultural machinery and equipment for sustainable straw management such as baler, direct seed drill, minimum/no-till seeder, handy straw cutter and straw block making equipment were proposed, equipped, and field tested at the respective pilot sites. The key successes and failures of the equipment operation and performance under local conditions were documented, and in several cases, adaptations/modifications were implemented to make improvements. Finally, training and demonstration on the agricultural machinery and equipment were provided to the farming communities at the pilot sites, alongside awareness-building on the negative impacts of residue burning and the benefits of sustainable agriculture (see Figure 4).



Figure 4. (from left to right) Demonstration of direct seed drill (Cambodia), handy straw cutter (Indonesia) and minimum/no-till seeder (Nepal). Respective pictures courtesy: Department of Agricultural Engineering, Cambodia; Universitas Gajah Maha Indonesia; and Tribhuvan University, Nepal.

During implementation of the pilot projects, two regional activities engaging all the pilots were organised by CSAM, which are described below.

### 1. Workshop and Virtual Demonstration on Mechanization Solutions for Straw Management

On 25 October 2022 a workshop and virtual demonstration on good practices in integrated and sustainable straw management was co-organised by CSAM, China Agricultural University and other local partners in Laixi, Qingdao, China, and broadcast live online to a regional/international audience (see Figure 5). The workshop had over 200 registered online participants and on-site attendees comprising of experts, academics, and practitioners from more than 30 countries alongside 50+ agricultural

machinery cooperative leaders, agricultural machinery operators, and farmer representatives.

The workshop delivered an overview of the implementation of and key results from the pilot project initiated earlier in Laixi, followed by sharing of good practices and experiences on integrated straw management by experts from India, Thailand, and Lao PDR. In the virtual demonstration session, a range of machinery and straw utilisation approaches applied in the Laixi pilot project were showcased including utilising straw for biogas production, production of organic fertilizer, utilization for fodder, cow manure separation, returning maize straw to the field as fertilizer and no-till planting of winter wheat, returning cow manure to the field as fertilizer, as well as returning solid and liquid residue from the biogas digester to the field as fertilizer.



Figure 5. Virtual Workshops and Demonstrations, 28 October 2020 & 25 October 2022, Laixi, China.

### 2. Study Tour on Mechanisation Solutions for Integrated Straw Management in Thailand

Thailand is an important producer of rice and has

extensive experience in dealing with rice straw residue. As part of the regional initiative, a study tour to Thailand was organised for 12 delegates from the Cambodia, Indonesia and Nepal pilot

sites, during 21 – 27 November 2022. The tour had the following objectives: 1) to demonstrate good practices and experiences on agricultural machinery-based solutions for integrated straw management in Thailand, and 2) to promote knowledge sharing, cross-learning and collaboration among the pilot teams from Cambodia, Indonesia and Nepal.

During the study tour, the delegations visited locations that actively implement agricultural machinery-based solutions for straw management, such as in Chai Nat and Cha Cheng Sao Province, Agricultural Learning Centre at Sam Ngarm Tar Boht, Straw Bale Business at Hankha District, Sak Pattana Combine Harvester Factory at Suphanburi, Rice Clusterfarm at Ban Nong Sang, Sanamchaiket District, and others.

They were exposed to the whole process of integrated rice straw management from preparing the land in rows with rice combine harvesters, soil preparation by rotary tillers to mix the stubble, straw decomposition and the application of bio-extract to accelerate the process, ‘Wet and Dry’ field technique to reduce GHG emissions from rice production, the applications of straw bales as fodder, fertilizer and base material, and straw bale collection operations, transportation and storage.

These visits demonstrated valuable practices from Thailand and promoted a better understanding of the circular model of straw management using machinery being promoted under CSAM’s regional initiative on integrated straw management.



Figure 6. Regional Study Tour on Mechanization Solutions for Straw Management, 21-27 November 2022, Thailand.

## IV. OVERALL RESULTS FROM THE PILOT PROJECTS

The pilot projects in Cambodia, Indonesia and Nepal achieved the following key results at the pilot sites in relation to their objective to promote the sustainable and climate-smart management of straw residue through use of agricultural machinery-based solutions:

1. Supported the laws/strategies/objectives of the respective national governments in relation to controlling the burning of straw residue.
2. Strong engagement of the local farming communities, including women groups, as well as change agents and their enhanced awareness about the environmental impact of burning straw.
3. Enhanced awareness about how machinery like the straw baler and direct seed drill as well as more simple equipment like handy straw cutter, mower and straw block making equipment,

enable integrated and climate-smart management of straw residue and bring economic and other benefits.

4. Dissemination of the results of the field trials of the machinery, including information on the efficiency of the machinery under local conditions.

5. Selected adaptations of the machinery to enhance performance in view of local needs.

6. Practical demonstration of the technical operation of the range of mechanization-based solutions in the field. Women farmers were especially engaged for promoting use of the machinery.

## V. KEY LESSONS LEARNED FROM THE PILOT PROJECTS

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### A. Main drivers for agricultural burning

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Burning of agricultural straw and residue in the field remains a widespread practice across the pilot sites, particularly in Cambodia and Nepal, for rapid, cheap and convenient removal before the next growing season. The project surveys revealed a range of drivers for agricultural burning practices. However, insufficient time for straw collection and lack of feasible alternative uses for the straw were two of the most common justifications cited by farmers. Further analysis of survey results in Nepal revealed that straw burning was related to the harvesting method, specifically combine harvester usage, which makes the residue more difficult to collect. Another common driver for burning across the Cambodia and Nepal sites, was a general decline in livestock farming, meaning that options for utilising the straw as fodder and bedding are similarly reduced. In some locations, it was found that a lack understanding of the adverse effects of straw burning was a contributing factor (in Cambodia) but in other locations (in Nepal) farmers continued to burn despite an awareness of the impacts. Overall, the results of the surveys suggested that the practice of burning can be eliminated by increasing the farmers' knowledge on and access to sustainable, integrated management and valorisation options for straw residue.

### B. Mechanization solutions to suit local needs and contexts

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Development of straw residue management programmes and implementation of technical solutions in farming communities should be conducted with specific consideration for the local conditions, straw commodities of the farms, and needs of the farmers. Each region and farming group has particular characteristics (topography, commodity, socioeconomic status, culture, education, and other demographics) that will affect the suitability of different agricultural machinery and practices. Considering these characteristics prior to implementation, will improve the success and effectiveness of the straw management solutions proposed.

### C. Engaging key stakeholders

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Directly engaging with relevant national, provincial, and community-level stakeholders is crucial to develop practical and impactful solutions for integrated straw management. During the pilot projects, the farming communities played vital roles in discussions, workshops, and planning, apprising the current farming situation at pilot sites and communicating their needs. With the productive input of all key stakeholders, sustainable straw management plans can be developed that are suitable, relevant, and beneficial for the farmers. Continued engagement, including provision of

training and demonstration of the proposed technical solutions and machinery to farming communities, will improve the success of implementation. Women were found to play an important role in farming across the pilot sites and so should be included in all aspects of engagement and training.

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#### **D. Testing and demonstration of machinery in the field**

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Testing of agricultural equipment and demonstration to farming communities in a local

context is of the utmost importance. Monitoring the performance of the equipment in the field will enable assessment of the compatibility between the machinery and the local agro-ecological conditions, and can ensure that information on machinery operation accuracy, efficiency, workload, and other variations in the field from local usage can be gathered and disseminated. Moreover, necessary technical and/or procedural adaptations can be identified and implemented to improve equipment efficiency under local conditions. In addition, comparing improved outcomes of using modern mechanized solutions in the field against those from traditional methods can further motivate farmers to adopt these solutions going forward.

## **VI. OVERARCHING POLICY RECOMMENDATIONS**

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### **A. International cooperation**

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Fostering cooperation among countries in South and Southeast Asia and in the Asia-Pacific region more broadly to exchange data and best practices can be crucial for strengthening national and international frameworks for management of agricultural residues and air pollution. Building regional/sub-regional alliances can aid success in monitoring and tackling transboundary air pollution. An example of such an alliance is the Association of Southeast Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution (AATHP) arising from peatland and forest fires<sup>[28]</sup>. Collaboration and coordination between national governments, local authorities, and farming communities can also lead to more effective action on agricultural residue burning.

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### **B. Monitoring air quality and agricultural burning hotspots**

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Enhanced long-term monitoring of air pollutants and agricultural burning hotspots, alongside open data sharing, is crucial to measure air pollution exposure and to identify the key polluting sources

and regions. Low-cost air pollution sensors can be combined with reference grade measurements to extend air quality monitoring networks across South and Southeast Asia, thus moving towards building a full-scale picture of regional air quality (e.g., OpenAQ<sup>[32]</sup>, IQAir<sup>[33]</sup> etc.). Advanced monitoring (using satellite and ground-based measurements) in combination with state-of-the-art computer modelling can be utilised to identify the most severe agricultural burning hotspots<sup>[34]</sup> to prioritize investments in sustainable agricultural mechanization programmes and to measure the resulting co-benefits.

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### **C. Prevention of agricultural straw residue burning**

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Increased regulation of agricultural residue burning should be introduced, including enforcement of open burning bans<sup>[35]</sup>. At the same time, further efforts should be made to raise awareness of the health and environmental risks of open burning amongst farming communities and the general public to discourage burning practices.

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## D. Mechanization solutions for integrated straw management

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It is essential to develop resources and provide technical training on sustainable agricultural mechanization that can make the collection of rice straw more manageable (such as through use of balers and direct seed drills) and can transform this 'waste' into a resource (eg. through biogas digesters). Widely promoting a circular model for rice straw management, promoting on- and off-site uses for crop straw residue, is vital to generate economic and environmental benefits for the farming communities.

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## E. Engagement and training of key stakeholders

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Active engagement with farming communities is vital to build and implement strategic plans and technical solutions for integrated straw management that are in line with the farmers needs and relevant for local contexts. Training on modern agricultural machinery and practices

should be provided to farmers under local conditions, demonstrating the additional benefits relative to methods already in use. Gender mainstreaming should be prioritized since women play an important role in farming and uptake of new technologies in South and Southeast Asia.

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## F. Aligning policies with the SDGs

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Preventing agricultural residue burning and enhanced application of agricultural machinery will help countries to achieve multiple SDG targets, including ensuring sustainable food production, equal access to new technology for poorer communities, and strengthening adaptive capacity to climate-related hazards. Mainstreaming gender in such programmes will also align them with SDG 5 (achieve gender equality and empower all women and girls) and help ensure the benefits reach women farmers and farm workers. The reductions in GHG emissions resulting from prevention of agricultural burning will support the attainment of SDG 13 (taking action to combat climate change), whilst also helping countries to uphold their commitment to The Paris Agreement.

# VII. SUMMARY & CONCLUSIONS

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Populations in South and Southeast Asia experience some of the highest air pollutant concentrations in the world, that are around 2 to 15 times the WHO Air Quality Guideline level. The sources of these air pollutants vary from country to country, province to province, and city to city. However, a constant underlying source, particularly in agrarian communities during the dry/post-harvest season, is the burning of agricultural straw residue in the field. While quick and efficient, burning can negatively impact climate, human health, soil health, and economies while further stratifying societies. Furthermore, these fires can easily spread to become uncontrollable wildfires, which can cause further ecological and environmental damage.

The practice of burning post-harvest straw residue is a major problem in South and Southeast Asia. Despite its negative consequences, it continues due to a lack of awareness and/or the

resources to make changes towards more sustainable practices. Through the CSAM regional initiative, lessons have been learned via close engagement with farming communities and other key stakeholders on the drivers of agricultural burning and on local farming needs and conditions. Knowledge was shared and gained on sustainable mechanization-based straw management solutions, appropriate for local contexts, that can effectively incentivise using straw residue as a resource and reduce burning.

If countries in South and Southeast Asia can find ways to avoid agricultural residue burning and reduce the amount of air pollutants and GHGs emitted from such burning, they can save lives, protect the environment, benefit farmers, and improve the overall productivity of their agriculture sectors.

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