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Reducing the Need to Burn: How Applying Sustainable Agricultural Mechanization in Nepal can Improve Air Quality

Picture courtesy: Tribhuvan University, Nepal

ESCAP

CSAM
Centre for Sustainable Agricultural Mechanization

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I. INTRODUCTION

Around seven million premature deaths are attributed to air pollution annually, including over 700,000 children[1]. In South Asia, air pollution exposure is a particular problem, with 100% of the population in India and Nepal – over 1.3 billion people – living in regions where fine particulate matter ($PM_{2.5}$) pollution exceeds the WHO[2] guideline level[3,4]. Yearly average $PM_{2.5}$ pollution concentrations in South Asian countries have remained persistently high, with concentrations in India, Nepal, and Bangladesh increasing in recent years (see Figure 1).

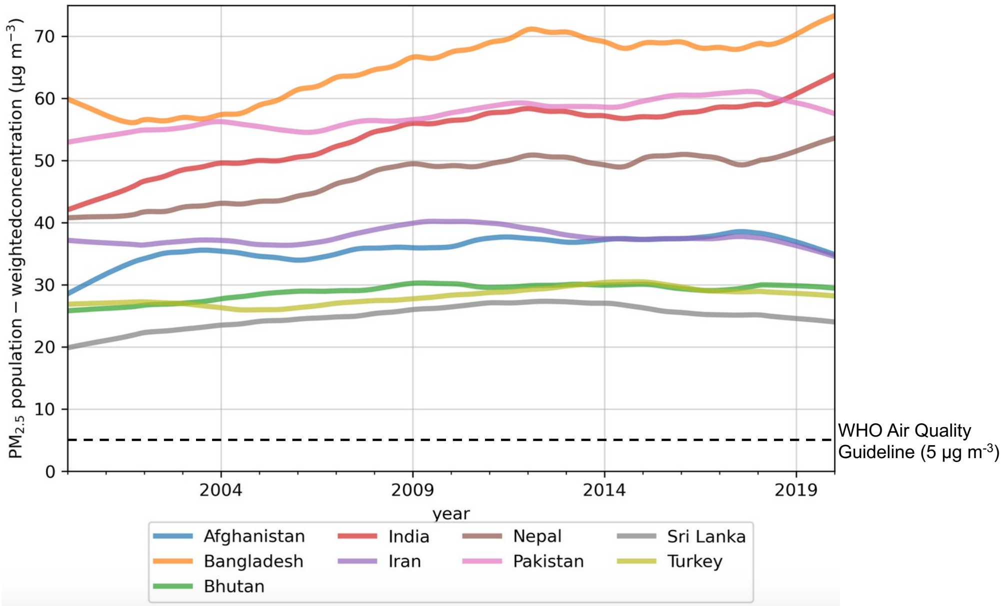

Figure 1. National population-weighted PM2.5 concentrations for West and South Asian countries between the years 2000 to 2020. Figure was produced using PM2.5 data from van Donkelaar et al.[5] and population data from CIESIN[6].

A major source of $PM_{2.5}$ exposure in South Asia is open burning of agricultural residues, particularly during burning seasons[7-9]. Agricultural residue burning in South Asia is also a large source of greenhouse gas (GHG) emissions[10,11]. Huge amounts of crop residues are burnt in South Asia every year, more than in any other sub-region (see Figure 2). In 2020, the amount of biomass dry matter burnt per square kilometre of agricultural land in South Asia was over two times that in North America and mainland China[12,13]. Exposure to $PM_{2.5}$ pollution from agricultural and forest fires is associated with adverse health outcomes including morbidity and mortality[14-17]. Preventing agricultural residue burning in South Asia could have a substantial human health benefit; avoiding around 44,000–98,000 premature deaths yearly across the sub-region[9].

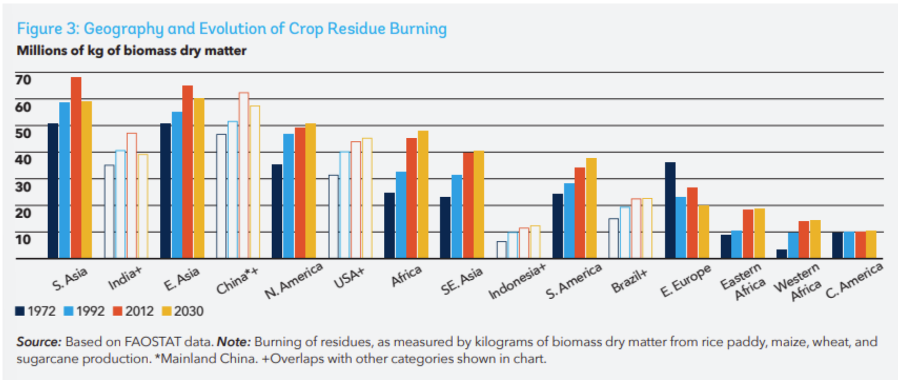

Figure 2. Geography and evolution of crop residue burning.

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[18]. Farmlands that have undergone repeated burning generally have reduced soil fertility[19] and higher erosion rates[20], requiring increased use of fertilizer[21]. However, viable no-burn alternatives exist that can provide both environmental and economic benefits to the farmers[22].

Implementation of modern agricultural machinery can promote the transition to sustainable and integrated management of agricultural residues, for example using baler machinery to compress and transport straw as bales for use as livestock feed/bedding, bioenergy, mushroom substrate, or industry material[23]. Once the rice straw has been harvested, using minimum/zero-till seeder (e.g., Happy Seeder) can help the farmers sow seeds in crop residue conditions, thus avoiding the need to first clear the field by burning.

Reducing air pollution from biomass burning in the agricultural sector in South 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.

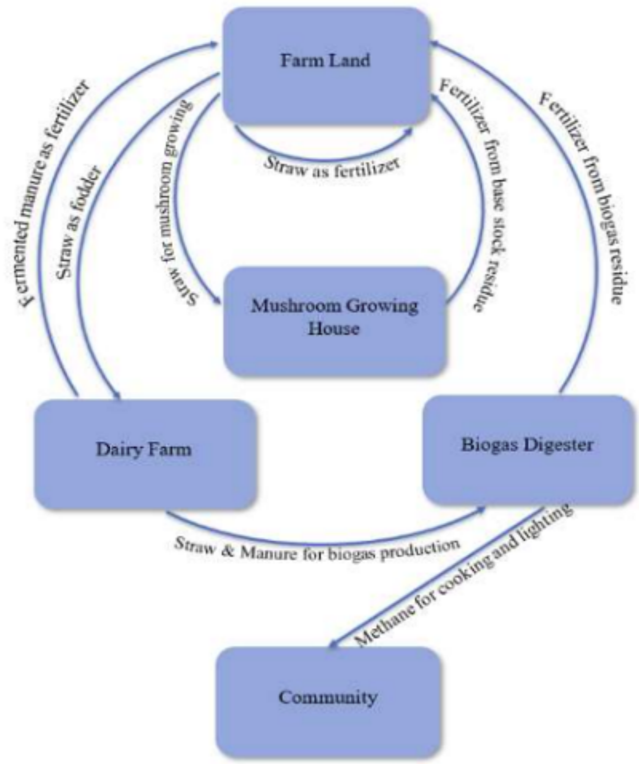

Figure 3. Circular model of straw utilisation.

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.

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.

B. Identifying key areas for interventions

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 mechanization should be prioritized to be most relevant.

C. Pilot on Integrated straw management in Nepal

This Brief on integrated straw management in Nepal analyzes the results of CSAM's pilot project in Morang district of Nepal's Province 1, including findings from local surveys about farming practices and the promotion of agricultural mechanization-based solutions to incentivize sustainably using straw residue as a resource. The pilot was implemented during 2021-2023 as part of a wider project titled *'Enabling Sustainable and Climate-smart Agriculture in Cambodia, Indonesia, and Nepal Through Mechanization Solutions for Integrated Management of Straw Residue and Air Pollution Monitoring'* with financial support from the China-ESCAP Cooperation Programme (CECP) and in partnership with Purwanchal Campus of Tribhuvan University, Nepal.

III. NEPAL: AGRICULTURE AND AIR POLLUTION

Nepal, situated in South Asia, was chosen for CSAM's pilot project as the agricultural sector is one of the most important sectors in terms of employment and the national economy. Nepal's agricultural sector involves two thirds of the working population and contributes around one quarter to one third of the national GDP[26]. In Nepal, paddy is the main staple crop, followed by maize, wheat, millet, buckwheat, and barley. Agricultural crop residues are mostly utilised as animal feed but residue burning in the field remains a common practice[27] (see Figure 4). Between 2 and 3 million tonnes of rice straw are subjected to burning yearly in Nepal[12,28], generating substantial air pollutant emissions[28] with severe implications for public health[9,15]. Agricultural fires can also spread from farms into forested land[29,30] causing further ecological and environmental damage. Therefore, there is an urgent need for the introduction of viable no-burn alternatives and the immediate implementation of agricultural mechanization-based solutions[27] to address residue burning practices in Nepal.

Figure 4. Farmers in Morang District, Nepal burning remaining paddy stubble (after combined harvester use) in the field. Picture courtesy: Tribhuvan University, Nepal.

A. Study Area: Morang District, Province 1, Nepal

In Nepal, paddy makes up around half of the total cereal crop production, with Province 1 accounting for around 23% of the total paddy production[31]. The CSAM project established its pilot site in Morang District, in south-eastern Nepal in Province 1, which is the one of the main paddy farming districts in Nepal. In 2021, Morang District was the second largest paddy producer of all districts in Nepal, producing 369,195 tonnes (around 7% of Nepal's total).

Morang District has a land area of 1,855 km2 and is in the Outer Terai (plains) of Nepal and borders with India to the south. Morang has a population of 1,147,186[31] and mostly consists of rural areas, with one metropolitan city (Biratnagar), eight municipalities, and eight rural municipalities. Most of Morang's land area (over 80%) lies in the lower tropical ecological zone with an elevation of under 300 m above sea level[32].

In Nepal's Terai region, increasing food demand has driven a recent increase in mechanization of agricultural processes, replacing more traditional methods. This mechanization provides multiple potential benefits to the farmers like increased production and decreased need for labour, but also some unintended consequences. Mechanized harvesting using machinery such as combine harvesters leaves longer stalks in the fields than manual harvesting methods[27]. With straw strewn around the field, collection becomes more challenging[33], which is compounded by an increased shortage of agricultural labour due to rising overseas employment and urban migration in Nepal[34]. A general reduction in livestock-keeping in the Terai means that options for utilising the straw as fodder and bedding are similarly reduced[27]. These factors combine to drive some Nepalese farmers to burn crop residues despite its adverse effects on air quality and the environment, thus indicating the need for implementation of mechanization-based solutions and viable alternative uses of crop residue in this region[27].

IV. CASE STUDY: IMPLEMENTATION OF MACHINERY IN MORANG

An agreement for implementation of the pilot project in Nepal was signed in 2021 between ESCAP and Purwanchal Campus, Tribhuvan University. The project was implemented in Morang District, Province 1, an important paddy farming district in Nepal where farmers lack feasible solutions to utilise post-harvest straw. The project aimed to deliver the following three outputs:

Output 1	Establish pilot site in Nepal for integrated management of straw residue informed by research on air pollution and GHG emissions from the agricultural sector.
Output 2	Test and adapt improved technologies and practices for integrated management of straw residue at pilot site.
Output 3	Enhance capacities of farming community and change agents for adopting improved technologies and practices for integrated management of straw residue.

The key project activities are summarised below.

A. Identification of Pilot Site

The field and plant of Krishna Daana Udhyog (KDU) (a local enterprise), located in Jhorahat, Biratnagar, Morang District, was selected to be the pilot site for in-situ and ex-situ management of straw residue. KDU was one of the stakeholders in this project, working in commercial cattle farming, animal feed production, and the making and supplying of nutrient-rich compressed straw blocks.

B. Identifying the current farming status in the study area

To understand the current agricultural straw uses and management practices in the study area, a baseline survey was conducted with 111 farmers (19% women) in Morang District, covering seven municipalities, two rural municipalities, and one metropolitan city. The survey was designed to determine the demographics of the farmers, the agricultural conditions of the farms, and the current straw management status.

The survey obtained a wealth of valuable information about the farmers and the local agricultural conditions in Morang District. In terms of agricultural mechanization, farmers in the surveyed area were found to be transforming farming practices from traditional to mechanized pattern. Tractors with tillage implements were being used for preparing fields, and threshers and combine harvesters had almost replaced manual threshing.

In terms of straw management, the survey identified that the main uses for straw post-harvest were for animal feed (45%), animal bedding (21%), and selling (12%). It was found that around 26% of the participating farmers burn the straw in the field, with the main justifications for using this practice being insufficient time for straw collection (32%) and lack of feasible alternative uses (30%) (see Figure 5). Almost all farmers indicated awareness and concern about the environmental impacts of straw burning. However, a lack of knowledge about straw valorisation left them with the only option of burning as a fast and convenient straw management option.

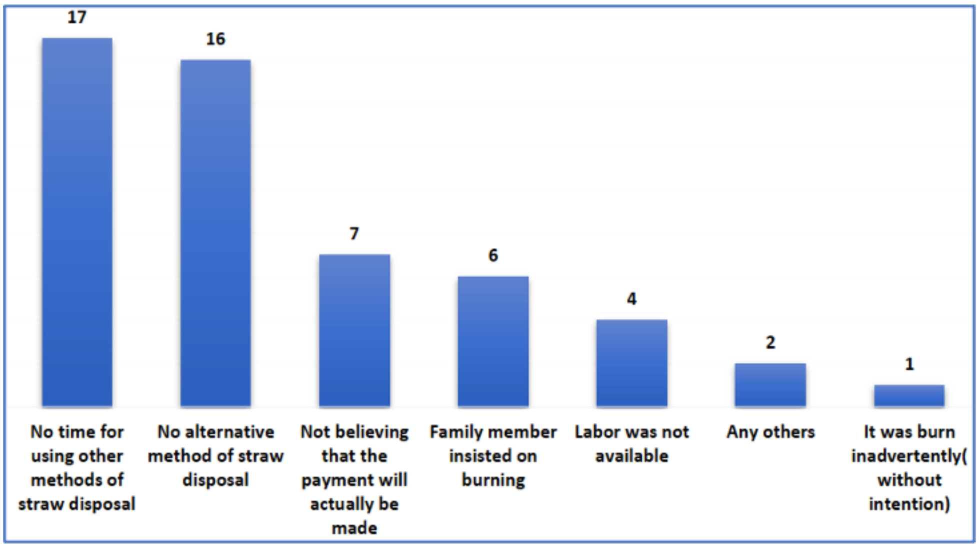

Figure 5. Baseline survey results showing the main reasons for farmers burning paddy straw in the field. Participants consisted of 111 farmers in the pilot project area of Morang District. Figure courtesy: Tribhuvan University, Nepal

Statistical analysis of the survey results revealed that straw burning was found to be related to the harvesting method, specifically combine harvester usage. The use of combine harvesters disperses the straw at random on the field, making the residue more difficult to manage[27], with straw collection serving to delay the following growing seasons and increasing economic cost (e.g., increased labour). Thus, the farmers keep the straw needed for animal feed in the absence of a valorisation alternative, while burning the remainder in the field. The analysis also found a strong link between farm location and residue burning, indicating that in some locations, such as Rangeli and Sunwarshi municipalities, high transportation costs to the site of demand cause a lack of buyers for the straw leading to farmers burning the excess. Finally, the analysis found that straw burning had no link to the educational level of the farmer, further indicating that the key driver for straw burning is the lack of alternative options.

C. Inception workshop

An inception workshop of the pilot project was organized, involving a total of 59 participants from the government, research institutes, academia and civil society, alongside entrepreneurs, farmers, and students. It benefited from the participation of relevant departments of the Government of Nepal as well as Province 1, Nepal Agriculture Research Council, United Nations Resident Coordinator's Office in Nepal, and other domestic stakeholders. The workshop highlighted the vital role of agricultural machinery in sustainable and integrated management of straw residue and briefed key national, provincial, and community-level stakeholders in Nepal about the pilot programme to enable their active support and engagement for producing practical, impactful outcomes suitable for the national context. The workshop successfully motivated participants, with 86% communicating a desire to learn more about or apply the solutions and practices highlighted in the event, and that they are looking forward to taking part in more such events in future.

D. Field trials of agricultural equipment

Field trials for in-situ straw management were conducted (see Figures 6,7 and 8) using machinery such as minimum/no-till seeders (Happy Seeder and Super Seeder) which can plant seeds directly through standing stubble, negating the need for the farmers to remove or burn the straw prior to planting. Trials were also conducted for the drum seeder, a low-cost and smallholder-friendly solution which can enable the crop to mature and be harvested earlier, allowing more time for the stubble to decompose before the next cropping cycle, thus discouraging burning.

Figure 6. Minimum/No-till Seeder (Super Seeder).

Figure 7. Left side control plot (traditional) & right side (Minimum/No-till Seeder) showing earlier maturity of the crop.

Figure 8. Drum Seeder.

(Pictures courtesy: Tribhuvan University, Nepal)

For ex-situ management of straw residue, an existing Total Densified Mixed Ration (DTMR) block making machine, used for making straw blocks for use as fodder or other purposes, was repaired/modified and operationalized.

E. Awareness building & demonstration sessions and training for machinery operators

Three awareness and demonstration sessions were organized to improve the farmers' understanding of the consequences of straw burning and to demonstrate improved ways of straw management. The sessions were conducted in parallel with the field trials, and involved presentations and discussions on straw burning and possible valorisation methods. Practical demonstrations of machinery such as minimum/no-till seeders, drum seeder, mulcher and straw block making machine were provided.

The sessions, which reached out to 194 farmers and change agents (27% women) were well received by the participants as evidenced by the results of the feedback questionnaires completed by them. For instance, 83% agreed or strongly agreed that the events achieved their objective of engaging stakeholders to promote integrated management of straw residue through agricultural machinery. Encouragingly, the vast majority of participants of all sessions (98%) indicated a strong interest in taking part in more such events in future.

In addition to the awareness sessions, training was given to KDU staff and local operators at the pilot site on operation and maintenance of in-situ and ex-situ straw management machinery. The training involved both theoretical and practical sessions, covering introduction of the machinery, its functions and major components, safety of the operator and machine, and repair and maintenance aspects. The training event was enhanced the capacity of all participants to implement improved technologies and practices for integrated management of straw residue.

F. Knowledge sharing visit (India)

To support the pilot project, a multi-stakeholder team of 7 delegates from Nepal visited India to gain knowledge of practices of straw management in the country. Through visits to agricultural research Institutes and universities as well as machinery manufacturers, the visiting team identified suitable agricultural machinery for in-situ straw management for the pilot site, learned about the approaches for reducing straw burning, and explored opportunities for cooperation and technology transfer on mechanization-based and other solutions for integrated management of straw residue and prevention of residue burning.

V. KEY RESULTS OF PILOT PROJECT IN NEPAL

The pilot project in Nepal achieved the following key results in relation to its objective to promote the sustainable and climate-smart management of straw residue through use of agricultural machinery-based solutions:

1. Reinforced understanding amongst farmers about the adverse consequences of crop straw burning and the economic benefits of valorization of the straw residue.
2. Enhanced skills of local machinery operators for smooth operation and maintenance of the machinery needed for sustainable in-situ and ex-situ utilization of straw such as minimum/no-till seeder, straw mulcher, baler and DTMR block making machine. Farmers cooperatives expressed willingness to buy such machines.
3. Enhanced capacities of the local farming communities (including women farmers), researchers and extension workers to implement improved mechanization

technologies and practices for integrated management of straw residue.

4. Improvements introduced to the DTMR straw block making machine leading to labour saving and reduced cost of production of straw blocks for ex-situ use.

5. Increased motivation among government stakeholders to promote minimum/no-till seeders for in-situ straw management, with the Directorate of Agricultural Research in at least one other location affirming plans to purchase the machinery for field trials and demonstration.

VI. POLICY RECOMMENDATIONS

A. Promote both in-situ and ex-site straw residue management

Organic content of the soils in Nepal is experiencing degradation in many places, so proper in-situ crop residue management through application of innovative machinery is necessary to improve the soil quality and hence productivity. In the absence of appropriate interventions, soil degradation may pose a challenge to food security in the coming years. In addition to in-situ management, opportunities for ex-situ use should also be explored, wherever practical and economically feasible, such as for briquette fuels, biogas production, carbonization fuel, gasification fuel, ethanol, mushroom growing, papermaking, building material and crafts production.

B. Expand and replicate pilot initiatives

Further replication and expansion of pilot initiatives such as the one implemented in Morang District are needed to draw wider-scale conclusions on the improvement of soil conditions under differing agro-ecological conditions, and to convince the farmers to adopt new or improved technologies and models over a larger geographic area.

C. Strengthen policy environment and government support

Enhanced government planning and strategies are needed to reduce straw burning and encourage straw based industries. There is need for policy support not only for offering viable alternatives to straw burning for farmers which can concurrently deliver economic benefits to them, but also for strengthening monitoring and enforcement measures to control burning.

D. Enhance sub-regional and regional cooperation

A range of good technologies, best practices and experiences on integrated and climate-smart crop residue management is available both in South Asia and in the Asia-Pacific region more broadly. There is continued need for enabling knowledge exchange and cooperation through multilateral as well as bilateral platforms and mechanisms so that effective actions and impact can be accelerated.

REFERENCES

1. GBD 2019 Risk Factors Collaborators (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet, 396, 1135–59. https://doi.org/10.1016/S0140-6736(20)30752-2.
2. WHO (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. License: CC BY-NC-SA 3.0 IGO. https://apps.who.int/iris/handle/10665/345329.
3. EPIC (2022a). The Energy Policy Institute at the University of Chicago. Air Quality Life Index (AQLI). Nepal Asia Fact Sheet. https://aqli.epic.uchicago.edu/wp-content/uploads/2021/09/Nepal-FactSheet_2022.pdf.
4. EPIC (2022b). The Energy Policy Institute at the University of Chicago. Air Quality Life Index (AQLI). India Asia Fact Sheet. https://aqli.epic.uchicago.edu/wp-content/uploads/2022/06/IndiaFactSheet_2022_Global-version.pdf.
5. Van Donkelaar, A. et al. (2021). Monthly Global Estimates of Fine Particulate Matter and Their Uncertainty. Environmental Science & Technology, 55 (22), 15287-15300. https://doi.org/10.1021/acs.est.1c05309.
6. CIESIN (2016). Center for International Earth Science Information Network - CIESIN - Columbia University. Gridded population of the world, version 4 (GPWv4): population count. Palisades, NY: NASA socioeconomic data and applications center (SEDAC). https://sedac.ciesin.columbia.edu/data/collection/gpw-v4.
7. Reddington, C. L. et al. (2019). Exploring the impacts of anthropogenic emission sectors on PM2.5 and human health in South and East Asia. Atmos. Chem. Phys., 19, 11887–11910, https://doi.org/10.5194/acp-19-11887-2019.
8. GBD MAPS Working Group (2018). Burden of disease attributable to major air pollution sources in India. Special report 21. Health Effects Institute. https://www.healtheffects.org/publication/gbd-air-pollution-india.
9. Lan, R. et al. Air quality impacts of crop residue burning in India and mitigation alternatives. Nat Commun 13, 6537 (2022). https://doi.org/10.1038/s41467-022-34093-z.
10. Venkatramanan, V. et al. (2021). Nexus Between Crop Residue Burning, Bioeconomy and Sustainable Development Goals Over North-Western India. Frontiers in Energy Research 8: 392. https://doi.org/10.3389/fenrg.2020.614212.
11. Ravindra, K. et al. (2019). Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. J. Clean. Prod. 208, 261–273. doi:10.1016/j.jclepro.2018.10.031.
12. FAOSTAT (2023). Amount of biomass dry matter burned by crop type data for 2020 from the Food and Agriculture Organization of the United Nations (FAO). License: CC BY-4.0. Available at: https://www.fao.org/faostat/en/#data/GB.
13. World Bank (2023). Agricultural land area data for 2020 from the Food and Agriculture Organization of the United Nations (FAO). License: CC BY-4.0. Available at: https://data.worldbank.org/indicator/AG.LND.AGRI.K2.
14. Jayachandran, S. (2009). Air quality and early-life mortality evidence from Indonesia's wildfires. Journal of Human Resources, 44, 916–954. https://doi.org/10.3386/w1401110.1353/jhr.2009.0001.
15. Chakrabarti, S. et al. (2019). Risk of acute respiratory infection from crop burning in India: estimating disease burden and economic welfare from satellite and national health survey data for 250 000 persons. Int. J. Epidemiol. 48, 1113–1124. doi:10.1093/ije/dyz022
16. Reid, C. E. et al. (2016). Critical review of health impacts of wildfire smoke exposure. Environmental Health Perspectives, 124(9), 1334–1343. https://doi.org/10.1289/ehp.1409277.
17. Vajanapoom, N. et al. (2020). Acute effects of air pollution on all-cause mortality: A natural experiment from haze control measures in Chiang Mai Province, Thailand. PeerJ, 8, e9207. https://doi.org/10.7717/peerj.9207.
18. Yutong, L. (2022). Head of the Center for Sustainable Agricultural and Mechanization (CSAM). Report on Inception Workshop on "Enabling Sustainable and Climate-smart Agriculture in Cambodia, Indonesia, and Nepal Through Mechanization Solutions for Integrated Management of Straw Residue and Air Pollution Monitoring", March 2022.
19. Lohan, S.K. et al (2018). Burning issues of paddy residue management in north-west states of India. Renew. Sustain. Energy Rev., 81, 693–706. https://doi.org/10.1016/j.rser.2017.08.057.
20. Santín, C. and Doerr, S. H. (2016). Fire effects on soils: the human dimension. Phil. Trans. R. Soc. B 371: 20150171. http://dx.doi.org/10.1098/rstb.2015.0171.
21. UNEP (2022). Toxic blaze: the true cost of crop burning. United Nations Environment Programme. Retrieved Jul 01, 2022, from https://www.unep.org/news-and-stories/story/toxic-blaze-true-cost-crop-burning.
22. Shyamsundar, P. et al. (2019). Fields on fire: alternatives to crop residue burning in India. Science, 365, 536–538. https://doi.org/10.1126/science.aaw4085.
23. UN ESCAP (2018). Status of straw management in Asia-Pacific and options for integrated straw management. ESCAP-CSAM. Retrieved from: https://hdl.handle.net/20.500.12870/4468.

24. Khanal, L. et al. (2020). Community vulnerability to epidemics in Nepal: A high-resolution spatial assessment amidst COVID-19 pandemic. Nepalese Journal of Zoology, 4(1), 23–35. https://doi.org/10.3126/njz.v4i1.30670.
25. https://opendatanepal.com/dataset/new-political-and-administrative-boundaries-shapefile-of-nepal
26. MoF (2022). Economic Survey, Fiscal year 2020/21. Ministry of Finance, Singh Durbar, Kathmandu Nepal. https://www.mof.gov.np/uploads/document/file/1633341980_Economic%20Survey%20(Engslish)%202020-21.pdf.
27. Bajracharya S.B. et al. (2021) Determinants of crop residue burning practice in the Terai region of Nepal. PLoS ONE 16(7): e0253939. https://doi.org/10.1371/journal.pone.0253939.
28. Das, B. et al. (2020). A model-ready emission inventory for crop residue open burning in the context of Nepal. Environmental Pollution, 266, 115069. https://doi.org/https://doi.org/10.1016/j.envpol.2020.115069.
29. Vadrevu, K. P. et al. (2019). Trends in vegetation fires in South and Southeast Asian Countries. Scientific Reports, 9, 7422. https://doi.org/10.1038/s41598-019-43940-x.
30. Nepal's forest fires - CIFOR Forests News. https://forestsnews.cifor.org/48187/nepals-forest-fires?fnl=en.
31. MOAD. 2022. "Statistical Information on Nepalese Agriculture 2020/21." Government of Nepal, Ministry of Agriculture & Livestock Development, Planning & Development Cooperation Coordination Division, Statistics and Analysis Section, Singhdurbar, Kathmandu, Nepal. https://moald.gov.np/wp-content/uploads/2022/07/STATISTICAL-INFORMATION-ON-NEPALESE-AGRICULTURE-2077-78.pdf.
32. Barnekow Lillesø, J-P. et al. (2005). The map of potential vegetation of Nepal: a forestry/agro-ecological/ biodiversity classification system. Center for Skov, Landskab og, Planlægning/Københavns Universitet. Development and Environment No. 2/2005. https://curis.ku.dk/ws/files/20497354/de2_001.pdf.
33. Balingbing, C. et al. (2020). Mechanized Collection and Densification of Rice Straw. In: Gummert, M., Hung, N., Chivenge, P., Douthwaite, B. (eds) Sustainable Rice Straw Management. Springer, Cham. https://doi.org/10.1007/978-3-030-32373-8_2.
34. Bossavie, L. and Denisova, A. (2018). Youth Labor Migration in Nepal. World Bank, Washington, DC. https://doi.org/10.1596/978-1-4648-1276-7_ch5.
35. https://explore.openaq.org/.
36. https://www.iqair.com/air-quality-map.
37. ASEAN (2021b). Association of Southeast Asian Nations. Roadmap on ASEAN Cooperation towards Transboundary Haze Pollution Control with Means of Implementation. Jakarta: ASEAN Secretariat, February 2021. https://asean.org/wp-content/uploads/2021/08/Roadmap-on-ASEAN-Cooperation-towards-Transboundary-Haze-17-Feb-21.pdf.
38. UNEP (2019). Air Pollution in Asia and the Pacific: Science-based Solutions. Climate and Clean Air Coalition (CCAC), United Nations Environment Programme (UNEP), and Asia Pacific Clean Air Partnership. https://www.ccacoalition.org/en/resources/air-pollution-asia-and-pacific-science-based-solutions-summary-full-report.