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Policy Brief

SUSTAINABLE AGRICULTURAL RESIDUE MANAGEMENT OPTIONS FOR SMOG REDUCTION

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INTRODUCTION

Air pollution, notably recurring annual smog episodes, continues to be one of the serious environmental and public health challenges in Pakistan, particularly in Punjab. Each year, particularly during October and November, air quality considerably deteriorates, as vehicular, industrial, agricultural, and other emissions from various sources coincide. Out of these, the open-field burning of rice residue after the Kharif harvest remains one of the tricky contributors. Open burning releases large quantities of smoke and harmful pollutants that aggravate the intensity of smog, adversely affect human health, and disrupt routine life and economic activity.

The government and relevant authorities have taken a number of initiatives including blanket bans, balloting-based limited subsidies, penalties, and public advisories. While these efforts have raised awareness to an extent, they have not prevented rice residue burning at scale. Reports have indicated that farmers are generally aware of the environmental and health consequences of open burning, but continue the practice because it is a fast and low-cost option. While various alternatives exist, their adoption is limited owing to a variety of barriers.

Because smog and residue burning are multifaceted problems, a multidimensional study, holistically integrating social, economic, environmental, and policy aspects of the problem, to identify sustainable and scalable solutions and devise data-driven policy recommendations is needed. However, such a systematic research for Pakistan is currently absent in the scientific and policy literature. To bridge this gap, the overarching aim of this project was to identify scalable and sustainable agricultural residue management and valorization solutions for Pakistan through conducting a multidimensional study comparing the baseline scenario (open burning) with alternative on-farm and off-farm rice residue management and valorization scenarios.

Accordingly, this policy brief is based on that project that holistically analyzed various rice residue management and valorization options using environmental, economic, and social assessments. The goal of this brief is to translate the research findings into policy guidance. Instead of proposing a wide array of interventions, the brief intentionally and primarily focuses on (the optimization of) three pre-existing instruments to enable sustainable on-farm transition: subsidy, loan, and penalty. This focused approach is adopted because these tools (which pre-exist but in suboptimal form), if

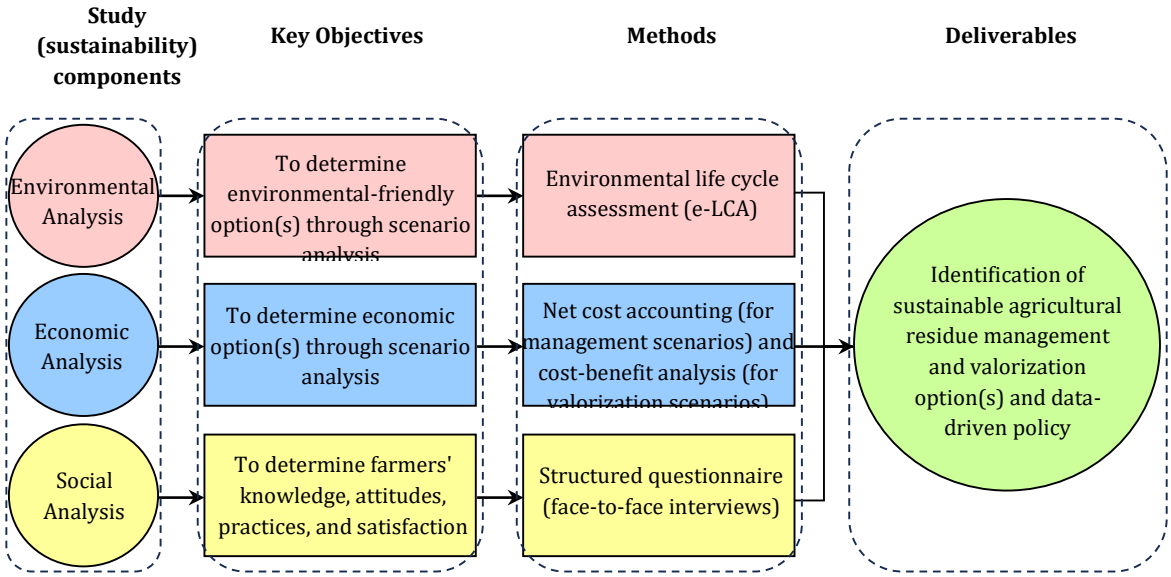
optimally designed and deployed, have the potential to significantly address the key barriers identified in the study without demanding a complete administrative or legislative overhaul. Accordingly, this brief presents an equitable and phased policy roadmap that recognizes differences among rice farmers, introduces enterprise-based residue valorization pathways, and emphasizes farmers' inclusion in policy improvement loop.

METHODOLOGY

An overview of the scope and framework of this study, comprising social, environmental, and economic components, is illustrated in Figure 1. The representative study area was Gujranwala, Punjab, which is a major rice-growing area where residue burning is the prevalent practice. The study compared five rice residue management scenarios: open-field burning (baseline scenario), shredder-based residue incorporation, direct sowing using a super seeder, compost production through composting, and biochar production through pyrolysis. The environmental assessment, carried out through an environmental life cycle assessment approach, compared how much each scenario contributes to environmental pollution and health-related impacts per tonne of rice residue managed. The economic assessment, comprising cost accounting and cost-profit analysis, provided costs incurred by farmers when adopting on-farm alternatives and assessed whether enterprise-based valorization pathways such as composting and pyrolysis can be financially viable. The social assessment, comprising a structured survey of rice farmers, was conducted to understand their grass root details, including demographics, satisfaction with existing government interventions, relevant knowledge, attitudes, and practices related to rice residue management. These multidimensional assessments were eventually integrated, enabling the identification of key barriers as well as corresponding solutions, thereby generating data-driven evidence essential for inclusive and sustainable policy-making.

Figure 1. Overview of Scope and Framework of the Study

Policy Brief



Source: Authors' compilations.

FINDINGS AND CONCLUSIONS

Amongst the on-farm residue management alternatives, super seeder was found to be the most environmental-friendly and least-costly option. Shredder-based pathway also helps minimize pollution but require additional agronomic operations, making them relatively less attractive in terms of cost. The existing eligibility criterion for subsidies on agricultural implements like super seeders and shredders is possession of a 65 hp tractor. However, 36% of the surveyed farmers do not own a tractor and are thus deprived of benefitting from such schemes. Importantly, field engagement with farmers revealed that these machines are effective only with high-powered tractors, preferably 85 hp. However, the findings revealed that ~60% of tractor owners have tractors with horsepower equal to or less than 75 hp. If these farmers with inadequately powered tractors purchase the aforementioned machines, they quickly revert to the practice of open burning due to suboptimal performance of the machines and narrow sowing times, thereby resulting in wastage of public money used on subsidies and lowering confidence of the farming community in government-led programs.

While options may exist for well-off farmers, small landholders are largely unable to adopt alternatives to open burning. As they are already disenfranchised, further penalizing them with heavy fines or arrests seems disproportionate. For those farmers to whom these on-farm alternatives are not feasible even with subsidies or loans, initiation of enterprise-based off-farm valorization models could be promising as these have the potential to help by paying farmers for residue and taking away the responsibility for processing. Both the off-farm enterprise-based residue valorization pathways, i.e., composting and pyrolysis, were found to be significantly better than open burning in terms of environmental improvement, and both are economically viable with composting being more profitable. Instead of farmer-led approaches, both these options are better

suited to private enterprises, as they require dedicated facilities besides residue collection, transport, and processing.

Meanwhile, it was found that farmers do have generic awareness of the harms of open burning and are also willing to adopt alternative technologies, however, actual adoption is constrained primarily by economic and structural barriers.

POLICY RECOMMENDATIONS

Based on the findings, this study recommends a phased policy framework focusing on subsidies, loans, and penalties applied in an equitable and sequenced manner. Because these instruments are already in use in the country to an extent, only optimization in their design and deployment is primarily proposed here as a minimal intervention to overcome the mismatch and misalignment with ground realities without asking for a complete overhaul. The goal is to first enable and empower, then scale, and eventually consolidate long-term behavioral change regarding sustainable agricultural residue management or valorization (Table 1).

During the *transition phase*, policy and programs should prioritize enabling farmers to transition away from burning by minimizing entry barriers. For farmers with no or low-powered tractors, subsidies and concessional loans should focus on increasing access to high-powered (≥85 hp) tractors (which are a critical prerequisite to successful operation of residue management machinery, e.g., super seeders) while for farmers owning adequate-powered tractors, these incentives should be available for residue management implements, e.g., super seeders and shredders. Considering some farmers may not be able to afford the full co-payment amount for subsidy at once, introducing an installment-based payment option would make the subsidy more accessible and reduce the immediate financial burden. Penalties should apply only to farmers who already have adequate technical and financial capacity to adopt alternatives. This entails meticulous scrutiny of eligibility of candidates for these incentives or penalties.

The *scaling phase* should gradually minimize subsidies while increasing enforcement as alternatives become largely accessible. Enterprise-based ventures, e.g., composting and pyrolysis, should be actively promoted, e.g., through concessional finance and tax rebates, allowing off-farm valorization pathways to flourish so that resource-constrained farmers could be relieved from the residue management burden. While these technologies are internationally-tested, it would be useful if these technologies are indigenized in due course through promoting relevant applied research and pilot-scale projects.

The *consolidation phase* aims for a matured system in which non-burning practices are accessible to most, if not all, farmers. During this stage, subsidies can be gradually withdrawn, loans can shift toward market terms, and penalties for burning can be applied across the board.

Table 1. ***Phased Policy Framework for Rice Residue Management***

Phase	Time Horizon	Target Farmers	Penalty	Subsidy	Loan / Financing

Policy Brief

Transition Phase	Short term (≤2 years)	Low-power tractor farmers	No	For high-powered tractors	Concessional loans for tractors
		High-power tractor farmers	Yes	For implements	Loans for implements
Scaling Phase	Medium term (≤5 years)	Low-power tractor farmers	Limited	Gradual reduction	Continued access to loans
		High-power tractor farmers	Yes	Targeted only	Market-linked loans
Consolidation Phase	Long term (≥10 years)	All farmers	Uniform enforcement	Gradual withdrawn	Commercial financing

Source: Authors' compilations.

Across all phases, policies should remain farmer-inclusive by systematically incorporating farmer feedback to adjust implementation over time. Although S-3 was found to have the lowest total annualized cost (including capital recovery), adoption barriers may be related to upfront capital access and machinery accessibility rather than long-term cost inefficiency. Alongside technology-based compliance monitoring (e.g., remote sensing and GIS tools for tracking burning), regular field engagement through agricultural extension departments, digital feedback mechanisms, and supervised student outreach programs can provide real-time insights into machinery performance, liquidity constraints, and adoption stability. This would enable support measures to be adjusted based on field realities and sustained uptake, rather than relying solely on time-bound phase implementation or compliance surveillance.

For realistic policy design, a few targeted follow-up assessments are advisable prior to large-scale implementation. These include externalities-based life cycle costing to compare fiscal burden and socio-environmental gains achieved through support measures; identifying practical adoption constraints such as capital access, adequate machinery availability, and labor dynamics; and validating enterprise-based pathways (e.g., composting and pyrolysis) through market-grounded analysis of plant scale, feedstock pricing, and product demand. Broader stakeholder consultations with farmers, machinery providers, potential investors and enterprises, financial institutions, and relevant departments would further help align incentives, financing mechanisms, and institutional roles. Such preparatory evidence and consultations would strengthen the feasibility and long-term sustainability of policy interventions aimed at transitioning away from residue burning in Gujranwala and similar districts in Pakistan.

Agriculture–related air quality improvement and smog mitigation are achievable when policies reflect farmer and market realities, enable an equitable and sustainable transition rather than relying solely on blanket enforcement, and promote complementary off-farm valorization and entrepreneurial pathways. This phased and equitable deployment of a diversified mix of on-farm and off-farm interventions therefore offers a pragmatic and evidence-based policy pathway toward sustainable agricultural residue management and valorization for associated smog reduction in Pakistan.