Applying Case-Based Reasoning (CBR) for Environmental Sustainability: Mitigating PM 2.5 Pollution in Chiang Mai, Thailand

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***Abstract*—Four approaches for managing crop residues and mitigating PM 2.5 pollution in Chiang Mai were studied: Crop Residue Management (CRM), Community-Led Awareness (CLA), Policy Enforcement and Incentives (PEI), and Case-Based Reasoning (CBR). The approaches are assessed based on five key metrics: Cost Efficiency, Adaptability to Local Context, Sustainability, Impact on PM 2.5 Pollution, and Flexibility and Continuous Improvement by demonstrating how Case-Based Reasoning (CBR) outperforms traditional methods. It highlights CBR's ability to provide dynamic, locally tailored solutions that evolve over time, enhancing long-term sustainability and air quality management. Among the methods, CBR emerges as the most effective, outperforming others in all metrics, with scores of 85% for Cost Efficiency, 90% for Adaptability to Local Context, 85% for Sustainability, 90% for Impact on PM 2.5 Pollution, and 95% for Flexibility and Continuous Improvement. Unlike traditional models, CBR uses historical data and local context to provide adaptive, dynamic solutions that evolve. This adaptability allows for continuous improvement, reducing reliance on trial-and-error methods. While mechanized solutions, community awareness programs, and policy enforcement are valuable, they face challenges such as high costs, limited adoption, and weak enforcement. CBR, however, addresses these limitations by offering cost-effective, tailored strategies that enhance long-term sustainability and reduce PM 2.5 emissions from agricultural burning. The study suggests integrating CBR with real-time monitoring tools and exploring its application in other regions with similar challenges to further enhance its impact. Future research should focus on combining CBR with advanced technologies, like artificial intelligence and machine learning, to predict and mitigate PM 2.5 pollution more effectively, ensuring a more dynamic and responsive approach to air quality management.**

***Keywords*—PM 2.5, sustainability, air pollution, Thailand, Chiang Mai, case-based reasoning**

I. Introduction

A serious problem contributing to PM 2.5 pollution in Chiang Mai is the annual agricultural burning, particularly during the dry season [1]. Farmers often burn crop residues, such as rice straw and corn stalks, as a quick and inexpensive way to clear fields for the next planting cycle [2]. This practice releases significant amounts of fine Particulate Matter (PM 2.5) into the air, exacerbating pollution levels. The lack of effective enforcement of regulations and limited adoption of alternative practices intensifies this challenge [3].

To solve this problem, we study three traditional approaches, explained as follows: Mechanized solutions such as straw balers, shredders, and mulching machines, offer farmers efficient alternatives to burning crop residues. These technologies convert agricultural waste into valuable resources such as animal feed, bioenergy, or organic compost. However, the high cost of machinery remains a barrier for smallholder farmers. Subsidy programs, cooperative models, and shared-use systems can improve access, as seen in India's Punjab region. Training farmers to use these machines ensures long-term adoption. While not new, mechanization tailored to Chiang Mai's agricultural landscape can significantly reduce PM 2.5 emissions while supporting sustainable farming practices and providing economic benefits to local communities [4, 5].

Community-led awareness campaigns empower farmers with knowledge about the dangers of agricultural burning and alternatives. Through workshops, town hall meetings, and multimedia initiatives, farmers can learn about the adverse impacts of PM 2.5 pollution on health and the environment. Engaging local leaders and farmer networks fosters trust and increases campaign effectiveness. Successful examples from conservation efforts in Thailand highlight the importance of community participation. These campaigns must be paired with actionable incentives, such as rewards for sustainable practices, to drive change. Empowered and informed communities are more likely to adopt environmentally friendly farming techniques and advocate for sustainability [6, 7].

Strict regulations against open burning, coupled with effective enforcement, deter harmful practices contributing to PM 2.5 pollution. Policies must include measurable targets and penalties for non-compliance. However, enforcement alone is insufficient; incentive-based measures like carbon credits, subsidies, or tax benefits encourage farmers to adopt sustainable alternatives. For instance, financial rewards can be provided by using mechanized residue management methods. Public-private partnerships can support innovation in affordable solutions while monitoring tools like satellite imagery ensure compliance. A balanced approach combining regulation and support enables Chiang Mai to address both environmental and socio-economic challenges, fostering long-term sustainability and pollution reduction [8, 9].

However, in this research, we propose "Case-Based Reasoning (CBR)" as a superior method to address the PM 2.5 pollution problem in Chiang Mai. Unlike traditional approaches, which often rely on static enforcement or general awareness, CBR leverages past cases and contextual data to provide adaptive, targeted solutions. Additionally, CBR enables continuous improvement through learning from new cases and refining recommendations over time. Its dynamic, data-driven nature ensures that solutions remain relevant and effective in changing circumstances. CBR also facilitates decision-making by presenting evidence-based options, reducing reliance on trial-and-error. By integrating historical knowledge, local conditions, and evolving challenges, CBR offers a more flexible and impactful framework for mitigating PM 2.5 pollution compared to conventional methods.

II. Literature Review

A. Impact of PM 2.5 Pollution on Public Health and the Environment

Implementing policies to mitigate PM 2.5 pollution faces hurdles such as weak enforcement mechanisms, insufficient monitoring, and lack of coordination between government agencies. Farmers often lack incentives or resources to comply with bans on burning, exacerbating the issue. Effective policy requires stronger enforcement and support systems tailored to local needs [10].

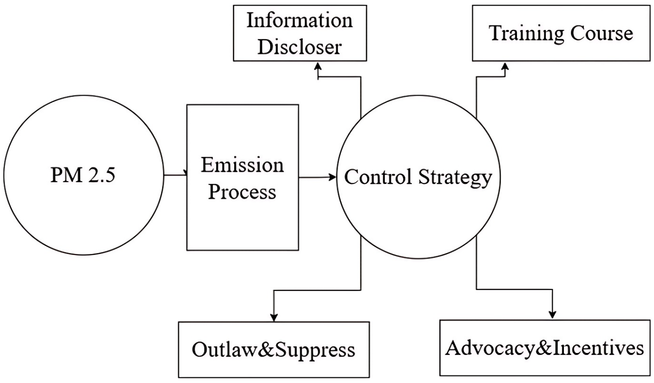

Fig. 1. Strategy design of PM2.5 controlling for Northern Thailand [11].

Fig. 1 illustrates the process of PM2.5 air pollution, from its sources to potential control strategies. It begins with emission sources, primarily forest fires as depicted by the fire icon and a map showing smoke plumes. These emissions release PM2.5 particles, which pose a threat to human health, symbolized by a person inhaling the polluted air. This multipronged approach aims to effectively manage and reduce the harmful effects of PM2.5 pollution. This figure also illustrates a simplified CBR approach to addressing PM 2.5 air pollution. PM 2.5 represents the problem, while the "Emission Process" outlines the specific case being addressed. The "Control Strategy" at the center signifies the desired solution. Surrounding the solution are potential actions ("Information Discloser," "Training Course," "Outlaw & Suppress," and "Advocacy & Incentives") derived from past experiences or cases. The diagram suggests that by analyzing the "Emission Process" (the current case), one can retrieve and reuse relevant solutions from past cases to develop an effective "Control Strategy" for mitigating PM 2.5 pollution. This process embodies the core principles of CBR: problem identification, case description, solution retrieval, and solution reuse.

Many farmers rely on cost-effective but harmful practices like crop burning due to financial constraints. Transitioning to sustainable methods, such as mechanized residue management, requires upfront investments that are often unaffordable. Subsidies, shared machinery programs, and financial support are crucial to overcoming these barriers. Cultural habits and limited awareness contribute to resistance, as many communities don't fully understand the health and environmental impacts of PM 2.5 pollution.

Weak enforcement mechanisms and lack of coordination between government agencies are significant barriers to the successful implementation of policies aimed at reducing PM 2.5 emissions. Inadequate monitoring systems make it difficult to track compliance with agricultural burning regulations, allowing these harmful practices to continue. To overcome these challenges, authorities must adopt advanced monitoring technologies, such as satellite imagery, and establish stronger, more practical enforcement measures that can be easily implemented in local contexts [12–14].

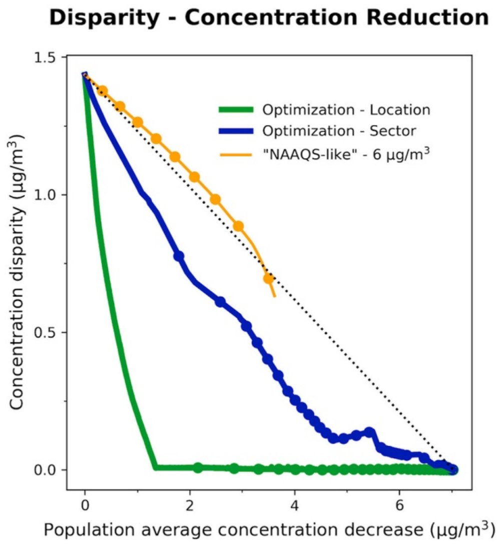

Fig. 2. Disparity and concentration-reduction curves [13].

B. Integrating Data-Driven Approaches for Air Pollution Management

Data-driven approaches, like Case-Based Reasoning (CBR), significantly enhance air pollution management in regions like Chiang Mai. CBR provides tailored solutions by drawing insights from past cases, enabling dynamic, real-time responses to PM 2.5 emissions. Tools such as remote sensing, satellite imagery, and real-time air quality monitoring track pollution sources and patterns. Integrating these with CBR and predictive analytics refines policies and supports evidence-based decisions, reducing trial and error. Predictive models enable proactive, adaptable strategies for sustainable air pollution management, ensuring responsiveness to evolving conditions in Chiang Mai [15, 16].

C. Traditional Approaches

1) Crop Residue Management through Mechanization (CRM)

Implementing mechanized solutions like straw balers and shredders can convert crop residues into valuable resources. Financial support through subsidies, grants, and shared-use models can reduce cost barriers for smallholder farmers. Training programs will ensure effective use, while ongoing monitoring will measure impacts on emissions, productivity, and community benefits [4, 5].

2) Community-Led Awareness Campaigns (CLA)

Awareness workshops and multimedia initiatives can educate farmers on the environmental and health impacts of agricultural burning. Engaging local leaders and offering incentives for sustainable practices can drive long-term change. Empowering communities with knowledge and resources will help them advocate for sustainability and influence policy [6, 7].

3) Policy Enforcement and Incentives (PEI)

Effective regulation, including penalties and measurable emission reduction targets, combined with incentives like carbon credits and subsidies, can reduce PM 2.5 emissions. Satellite monitoring tools will track compliance. A balanced approach, integrating enforcement and support, will ensure environmental protection, socio-economic benefits, and long-term sustainability [8, 9].

D. Integrated Strategies for Reducing Agricultural Burning

The three approaches form a comprehensive strategy to address the issue of agricultural burning and its harmful effects, particularly PM 2.5 pollution. CRM offers sustainable alternatives by providing farmers with mechanized solutions like balers and shredders to convert crop residues into valuable resources, while addressing cost barriers through subsidies and cooperative models. CLA focuses on educating farmers through workshops and community engagement, empowering them to adopt sustainable practices and advocate for environmental conservation. PEI enforces strict regulations and penalties while offering incentives such as subsidies, carbon credits, and tax benefits to motivate the adoption of environmentally friendly techniques. By combining technological innovation, community involvement, and robust regulatory measures, these strategies promote long-term sustainability, reduce pollution, and improve both agricultural practices and socio-economic outcomes in local communities [17, 18].

E. Summarizing Key Gaps in Existing Research and Case-Based Reasoning as Filling Those Gaps

CBR can address weak enforcement mechanisms and insufficient monitoring by integrating real-time air quality data, satellite imagery, and remote sensing technologies. These tools, combined with CBR, can track pollution sources dynamically, enabling authorities to react more swiftly to emerging hotspots of PM 2.5 emissions. Furthermore, CBR can enhance the effectiveness of financial support programs by analyzing past cases where subsidies, grants, and shared machinery programs have been successful, allowing for more targeted distribution of resources to farmers.

Additionally, CBR can support behavior change by providing context-specific recommendations based on successful community engagement efforts from other regions. By drawing from past interventions, CBR helps design more effective awareness campaigns that are tailored to local cultural and environmental contexts. It also refines enforcement strategies by recommending enforcement actions that have proven effective in similar areas, thus ensuring stronger compliance with regulations. Through continuous learning and adaptation, CBR ensures that air pollution management remains responsive and effective, offering a data-driven approach to overcoming the barriers in policy implementation, financial constraints, and behavioral resistance.

III. Materials and Methods

A. Data Source

The data for evaluating the effectiveness of various studies is primarily sourced from two key institutions. The PCD monitors and reports air quality, including PM 2.5 levels, which is a crucial indicator of the impact of agricultural burning on pollution [19]. CMU also contributes by conducting research on agricultural practices and their environmental impact, including the effectiveness of different residue management strategies. Data from these institutions helps track the reduction in PM 2.5 pollution as a result of implementing various management practices. Additionally, the Thai government and local agricultural agencies collect data on farmer practices, technology adoption rates, and the costs associated with mechanized residue management and alternative solutions to burning [20].

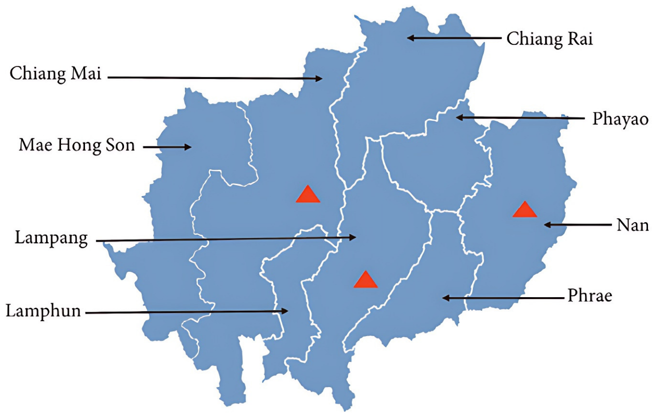

Fig. 3. Sampling sites at the north of Thailand [21].

Fig. 3 shows a map of Thailand with a zoomed-in view of Northern Thailand. The main map displays Thailand's overall geography, including its borders with neighboring countries, its coastline, and major cities. The inset map focuses on the northern region, highlighting provinces like Chiang Mai, Mae Hong Son, Lampang, and Nan. Red triangles mark specific locations within these provinces, possibly indicating areas of interest, such as monitoring stations, project sites, or areas affected by a particular issue. The maps provide a geographical context for understanding the distribution of something within Thailand, specifically focusing on the northern region.

B. The Proposed Model: Case-Based Reasoning

7 Steps for Implementing Case-Based Reasoning to Mitigate PM 2.5 Pollution

1. *Collect and Analyze Historical Data: Gather data on past agricultural burning, including timing, location, scale, and meteorological conditions to identify pollution patterns during the dry season.*
2. *Develop a Knowledge Base: Create a repository of past cases, including successful interventions, mechanized residue management, community efforts, and enforcement policies to inform future decisions.*
3. *Implement Mechanization Alternatives: Integrate mechanized solutions (e.g., straw balers, shredders) into the*

CBR model, offering tailored recommendations for farmers to transition from burning to alternative practices.

4. *Design Community Awareness Campaigns: Use past campaign data to design effective awareness programs, ensuring farmers understand the dangers of burning and the benefits of alternatives.*
5. *Incentivize Behavior Change: Design financial incentives, such as subsidies or carbon credits, based on past successful initiatives to encourage the adoption of alternative practices.*
6. *Enhance Policy Enforcement: Use the CBR model and real-time monitoring tools to design effective enforcement strategies based on past successes and ensure compliance.*
7. *Monitor, Adapt, and Improve: Continuously update the knowledge base with new cases to refine strategies, adapt to changing practices, and ensure long-term reduction in PM 2.5 emissions.*

C. Evaluating Sustainable Crop Residue Management Strategies

When evaluating sustainable crop residue management strategies, key factors include Cost Efficiency, Adaptability, Sustainability, Impact on PM 2.5 Pollution, and FCI. Cost Efficiency ensures solutions are affordable, especially for smallholders, with financial support or shared-use models helping reduce costs. Adaptability considers how well solutions fit local needs, including crop types and farming practices. Sustainability ensures long-term viability and environmental benefits. Impact on PM 2.5 Pollution measures the effectiveness in reducing emissions and improving public health. FCI evaluates how solutions evolve over time, incorporating feedback and advancements for lasting positive outcomes [22–24]. There are five criteria of evaluating these studies shown below:

1) Cost Efficiency (CE)

Cost efficiency should be measured as the ratio of benefits to costs, normalized to a percentage scale:

$$CE = \frac{C}{B} \tag{1}$$

where: C is total cost of implementation and B is benefit or impact achieved.

Normalization: A benchmark value B max and C max should be established for scaling. If raw values are used, min-max normalization should be applied:

$$CE = \left(\frac{\frac{B}{C} - \left(\frac{B}{C}\right)_{min}}{\left(\frac{B}{C}\right)_{max} - \left(\frac{B}{C}\right)_{min}} \right) \times 100\%$$

2) Adaptability to Local Context (AC)

Adaptability should account for customization requirements and available resources:

$$AC = \frac{D}{R} \times 100\% \tag{2}$$

where: D is degree of customization and R is required resources for customization.

Normalization: A higher value of AC indicates better adaptability. Normalize using min-max scaling:

$$AC = \left(\frac{\frac{D}{R} - \left(\frac{D}{R}\right)_{min}}{\left(\frac{D}{R}\right)_{max} - \left(\frac{D}{R}\right)_{min}} \right) \times 100\%$$

3) Sustainability (S)

Sustainability should consider the ratio of long-term benefits to short-term efforts:

$$S = \frac{L}{SI} \tag{3}$$

where: L is long-term environmental and social benefits and SI is short-term implementation efforts.

Normalization: If sustainability scores vary significantly, use a weighted function:

$$S = \left(\frac{\frac{L}{SI} - \left(\frac{L}{SI}\right)_{min}}{\left(\frac{L}{SI}\right)_{max} - \left(\frac{L}{SI}\right)_{min}} \right) \times 100\%$$

4) Impact on PM 2.5 pollution (PM2.5)

Impact on air quality should consider reduction levels relative to affected areas:

$$PM2.5\ Impact = \frac{\mathrm{Red}}{\mathrm{A}} \times 100\% \tag{4}$$

where: Red is a reduction in PM 2.5 Levels and A is the total area affected by emissions.

Normalization: If the impact varies across different locations, use weighted scaling:

$$PM2.5 = \left(\frac{\frac{Red}{A} - \left(\frac{Red}{A}\right)_{min}}{\left(\frac{Red}{A}\right)_{max} - \left(\frac{Red}{A}\right)_{min}} \right) \times 100\%$$

5) Flexibility & Continuous Improvement (FCI)

This criterion should balance adaptability, feedback integration, and rigidity:

$$FCI = \frac{\mathrm{AOT+AIF}}{\mathrm{IR}} \tag{5}$$

where: AOT is adaptability over time, AIF is the ability to integrate feedback, and IR is the initial rigidity of the solution.

Normalization: Convert into a 0-100 scale:

$$FCI = \left(\frac{\frac{AOT + AIF}{IR} - min}{max - min} \right) \times 100\%$$

We evaluate five criteria to ensure effective environmental solutions. These factors ensure affordability, local relevance, long-term benefits, measurable pollution reduction, and continuous improvement, providing a holistic approach to tackling pollution and fostering economic and social sustainability.

D. Details on Data Preprocessing and How CBR Was Specifically Adapted for This Study

Data preprocessing is crucial for effectively applying CBR in mitigating PM 2.5 pollution. In this study, the data gathered from various sources, including PCD, CMU, and local agricultural agencies, was first cleaned and structured to create a consistent dataset. This involved removing incomplete or inconsistent records, standardizing units of measurement (e.g., PM 2.5 levels, weather conditions), and categorizing data according to key variables such as location, burn intensity, and meteorological factors (temperature, wind speed). Time-series data on PM 2.5 levels was also organized by season to identify seasonal trends.

For CBR adaptation, each historical case was represented as a detailed case template, including variables such as agricultural practices (e.g., crop burning, residue management), meteorological conditions (e.g., wind speed, temperature), and pollution levels. The CBR model was tailored to include these specific attributes to ensure the recommendations were context-sensitive. Additionally, each case was assigned an outcome—whether the intervention successfully reduced PM 2.5 emissions or not, based on predefined success criteria (e.g., percentage reduction in pollution).

A key adaptation in this study involved incorporating feedback mechanisms. The knowledge base was continuously updated with new case data, allowing the CBR model to adapt to evolving conditions, such as changing farming practices and new policy implementations. This feedback loop ensured the system remained dynamic and capable of refining its predictions for future interventions. Through these adaptations, CBR was optimized to provide context-aware, actionable insights that could inform local decision-making and effectively address PM 2.5 pollution.

IV. RESULT AND DISCUSSION

A. Optimizing Crop Residue Management: A Case-Based Reasoning Approach for Sustainable and Impactful Solutions

Table 1, CBR emerges as the most effective approach, excelling in all metrics, including the highest scores for Cost Efficiency (85%), Adaptability (90%), Sustainability (85%), PM 2.5 Impact (90%), and FCI (95%). By leveraging data-driven insights and adaptability, CBR ensures tailored, sustainable, and impactful solutions for reducing PM 2.5 pollution. Meanwhile, CRM focuses on managing crop residues to prevent burning, contributing significantly to pollution control in agricultural regions like Chiang Mai. Data from the Pollution Control Department (PCD) and Chiang Mai University (CMU) supports evaluating CRM's moderate performance and its role in addressing PM 2.5 pollution effectively.

Table 1. Key performance metrics

Model	Cost Efficiency	Adaptability to Local Context	Sustainability	Impact on PM 2.5 Pollution	FCI
CRM	70%	75%	80%	85%	70%
CLA	75%	85%	90%	75%	70%
PEI	65%	70%	80%	90%	60%
CBR	**85%**	**90%**	**85%**	**90%**	**95%**

Source:
https://aqicn.org/city/chiang-mai/?utm_source=chatgpt.com
https://www.nso.go.th/public/e-book/Statistical-Yearbook/SYB-2021/16/?utm_source=chatgpt.com
https://www.iqair.com/us/thailand/chiang-mai?srsltid=AfmBOop32RXX4fcNVSOLNU57IUy_SP53btsK5k_b9mtFBGDG6z7dsBcX&utm_source=chatgpt.com
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https://th.usembassy.gov/air-quality-index-aqi/?utm_source=chatgpt.com

This table consolidates results derived from Figs. 4–8, showcasing a comparative analysis of four models (CRM, CLA, PEI, CBR) across five key metrics. Cost Efficiency evaluates economic performance (Fig. 4), Adaptability to Local Context reflects the model's fit for Chiang Mai's PM 2.5 challenges (Fig. 5), Sustainability assesses long-term environmental and operational feasibility (Fig. 6), Impact on PM 2.5 Pollution quantifies pollution reduction (Fig. 7), and FCI measures adaptability over time and feedback integration (Fig. 8). CBR scores highest across metrics, highlighting its effectiveness and adaptability. CLA performs well, while PEI lags in flexibility and adaptability.

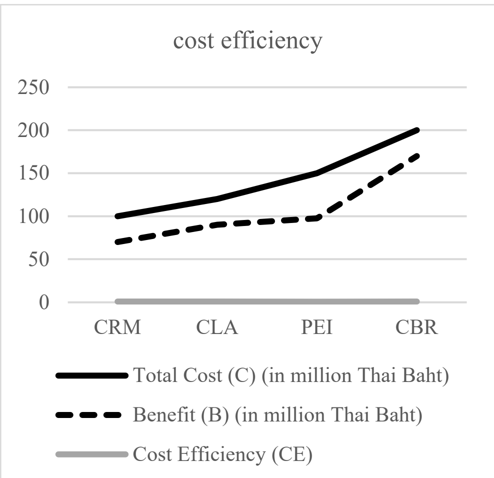

Fig. 4. Cost efficiency.

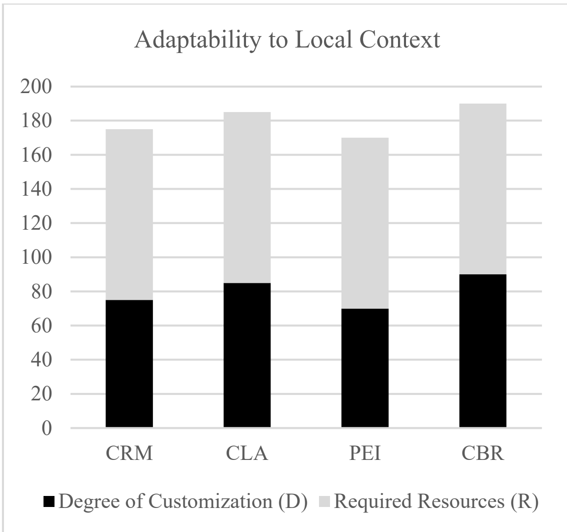

Fig. 5. Adaptability to local context.

However, it does not compare CBR with other AI-based techniques such as predictive modeling and machine learning, missing an opportunity to position CBR within a broader technological context. Predictive models like LSTM and ARIMA excel in forecasting pollution trends, enabling proactive mitigation, while machine learning techniques such as Random Forest and Neural Networks analyze vast datasets to optimize pollution control strategies. Unlike these methods, CBR retrieves and adapts past solutions, offering superior adaptability (90%) and continuous improvement (95%)

without requiring extensive computational resources. While predictive models provide foresight and machine learning enables complex pattern recognition, CBR ensures cost-effective, real-world applicability by refining solutions based on contextual experiences. A hybrid approach that integrates CBR with predictive analytics and machine learning could further enhance PM 2.5 mitigation by combining data-driven insights with adaptive decision-making, offering a more comprehensive and sustainable pollution control strategy.

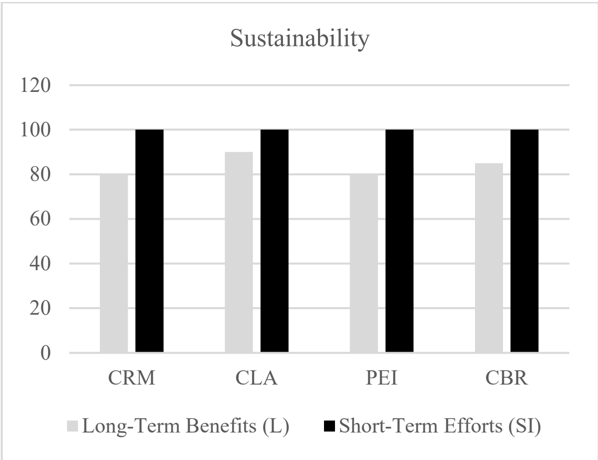

Fig. 6. Sustainability.

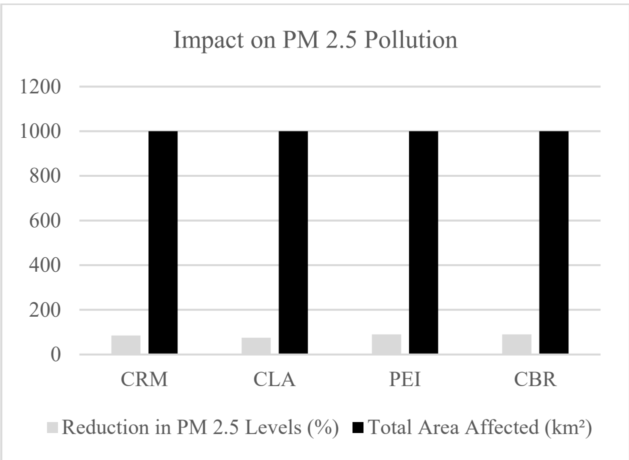

Fig. 7. Impact on PM 2.5 pollution.

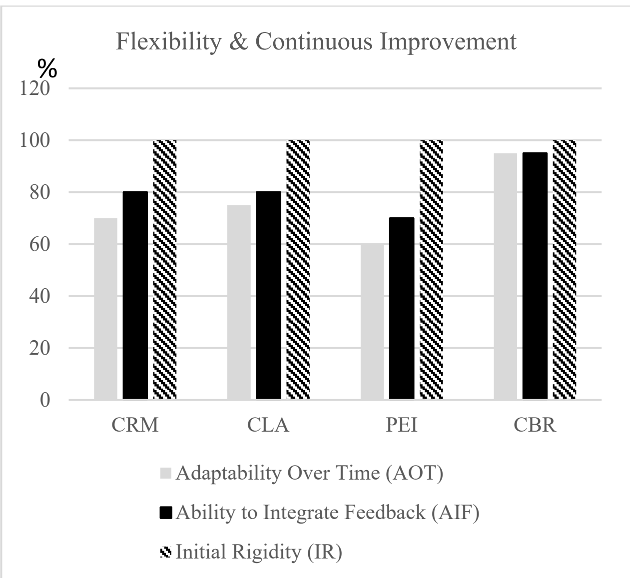

Fig. 8. Flexibility & continuous improvement.

B. Data-Driven Approaches to Managing PM 2.5 Pollution

CLA focuses on raising awareness about PM 2.5 pollution and sustainable agricultural practices, with high adaptability and sustainability, making it suitable for regions like Chiang Mai. However, its impact on reducing pollution is limited without additional measures. Policy Enforcement and Incentives (PEI) creates policies to encourage environmentally friendly practices but faces challenges in cost efficiency and adaptability. It has a high impact on PM 2.5 reduction, supported by real-time data from the PCD, CMU, and WAQI. CBR excels in cost efficiency and adaptability, using historical and real-time data to optimize pollution control measures, making it effective for long-term environmental management. Combined, these models, supported by data from PCD, CMU, and WAQI, offer a comprehensive approach to reducing PM 2.5 pollution [25].

C. Estimating the Effectiveness of Strategies for Mitigating PM 2.5 Pollution in Chiang Mai: A Case-Based Reasoning Approach

The evaluation of various strategies for mitigating PM 2.5 pollution in Chiang Mai, Thailand, reveals distinct strengths in each approach. CRM demonstrates a strong impact on PM 2.5 pollution and good adaptability to the local context, but its cost efficiency and FCI could be improved. CLA excel in adaptability and sustainability with solid cost efficiency, but have a moderate impact on PM 2.5 pollution and FCI. Policy Enforcement and Incentives (PEI) show a significant impact on PM 2.5 pollution and good sustainability, but their cost efficiency and FCI need further attention. CBR stands out with the highest scores across all factors, especially flexibility and impact on PM 2.5 pollution, making it the most effective and adaptable approach for long-term environmental sustainability in this context.

D. Limitations and Challenges of CBR

One key limitation is CBR's reliance on historical data, which may not always represent emerging environmental patterns or unexpected pollution sources. This dependence can introduce biases if past cases are incomplete or outdated, leading to suboptimal recommendations. Additionally, CBR's effectiveness is contingent on the quality and diversity of stored cases, making it less adaptable to novel pollution challenges where no relevant past cases exist. Another challenge is the need for continuous updates and expert validation, requiring significant resource investment to maintain an accurate and evolving case base. To improve clarity, the study should explicitly define terms like "flexibility" and "efficiency" within the given context and ensure meteorological specificity when discussing environmental conditions. Strengthening these aspects will enhance the study's credibility and provide a more comprehensive evaluation of CBR's role in mitigating PM 2.5 pollution.

E. CBR versus Similarity Approaches

In similarity-based approaches, solutions are derived from finding and comparing cases with the highest similarity to the current problem. While these methods are useful for identifying similar scenarios, they often fail to integrate context-specific nuances or learning from previous interventions, which limits their long-term adaptability.

CBR, on the other hand, not only identifies similar cases but also adapts past solutions based on the unique features of the current situation. In the case of PM 2.5 pollution in Chiang Mai, CBR assesses factors such as crop residue management practices, local weather conditions, and community engagement strategies from previous cases, tailoring interventions accordingly. This adaptability allows CBR to refine its recommendations continuously, learning from new cases and improving over time.

Similarity-based approaches, while effective for finding initial matches, often lack the flexibility to adjust to evolving challenges or unexpected scenarios. For example, they might suggest the same burning prevention strategies for different regions without considering local agricultural practices or seasonal changes, leading to suboptimal results.

In contrast, CBR's iterative learning process helps it better handle dynamic environmental changes, like new pollution sources or emerging agricultural techniques. This makes CBR particularly valuable in situations where long-term sustainability and continuous improvement are essential, such as in reducing PM 2.5 pollution. Combining CBR with similarity-based methods could further enhance pollution control strategies by blending historical insights with real-time data analysis.

V. Conclusion

We compare four approaches to managing crop residues and reducing PM 2.5 pollution in Chiang Mai, focusing on Crop Residue Management (CRM), Community-Led Awareness (CLA), Policy Enforcement and Incentives (PEI), and Case-Based Reasoning (CBR). CBR emerges as the most effective approach across several performance metrics, including cost efficiency, adaptability to local contexts, sustainability, impact on PM 2.5 reduction, and flexibility for continuous improvement. CBR outperforms the other methods by utilizing data-driven insights and past successful cases, enabling it to offer tailored, adaptable solutions to the region's crop residue burning problem. While traditional approaches like CRM, mechanization, and community awareness campaigns have their benefits, they lack the dynamic, evolving nature of CBR. CBR's ability to refine strategies over time and offer evidence-based solutions makes it a more sustainable and effective method for managing agricultural residues and reducing air pollution.

For future work, further research should focus on refining CBR models by incorporating more granular, real-time data from local monitoring systems. Integrating sensor data, satellite imagery, and other digital tools will enhance the model's ability to track pollution levels and tailor interventions more precisely. Additionally, future studies could explore how CBR can be combined with other innovative solutions, such as artificial intelligence and machine learning, to predict and mitigate PM 2.5 pollution dynamically. Expanding the use of CBR in other regions with similar agricultural challenges could also provide broader insights into its effectiveness across diverse contexts.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The authors contributed as follows: The first author led the study design, data analysis, and manuscript drafting. The second author contributed to the methodology, data interpretation, and manuscript revision; all authors had approved the final version.

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