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Winter Air Quality Challenges In Urban Cold Climates: Policy Benchmarking And Implementation Insights For Camca

Oyuntugs Batbaatar, Tuguldur Yanjiv, Batkhurel Gombodorj
Mongolian University of Science and Technology (MUST), Mongolia, 2025

Abstract
Severe winter air pollution remains a critical challenge in cold-climate urban regions, where domestic heating, stagnant weather conditions, and limited regulatory capacity combine to degrade air quality. This study conducts a cross-national benchmarking analysis of air pollution policy implementation across 13 cold-climate countries—including the U.S., Canada, Germany, Finland, Poland, China, Korea and Japan—to identify effective legal, institutional, and governance practices for managing winter-specific air quality issues. The objective is to derive actionable insights for countries in the Central Asia, Mongolia, and Caucasus (CAMCA) region, where urban air quality challenges are acute but policy responses remain underdeveloped.

Using a mixed-methods approach that combines legal review, policy evaluation, and governance indicators, the study assesses how high-performing countries operationalize air pollution control through statutory mandates, performance-based regulatory cycles, enforcement mechanisms, and public participation. A policy implementation framework is applied to selected CAMCA urban centers to evaluate current practices and identify institutional and legal gaps.

Results show that effective winter air quality governance relies on integrated planning, science-based monitoring, inter-sectoral coordination, and strong public accountability. In contrast, CAMCA countries often face fragmented responsibilities, weak enforcement, and limited use of real-time data in decision-making. The paper concludes by proposing a policy benchmarking model and reform roadmap tailored to CAMCA's urban governance context, aiming to support the development of adaptive, health-protective air quality systems in cold-climate developing regions.

Keywords: *Winter air pollution, CAMCA region, Mongolia, Central Asia, air quality governance, environmental policy, public policy, public participation, public-private partnership, new public governance, new public management*

1. INTRODUCTION

Winter air pollution remains a persistent public health and environmental challenge in urban centers across Central Asia, Mongolia, and the Caucasus (CAMCA), largely driven by household coal combustion, biomass use, and meteorological conditions that exacerbate particulate matter concentrations ($PM_{2.5}$, PM_{10}) during the cold season (Sumiya et al., 2022; WHO, 2021; Mamasadykova, 2024; UNEP, 2023). Mongolia and several other Asian countries consistently exceed WHO air quality guidelines, contributing to elevated rates of respiratory and cardiovascular diseases, premature mortality, and substantial economic losses (WHO, 2018; World Bank, 2025; Guttikunda et al., 2023). Although CAMCA countries have introduced air quality legislation and mitigation strategies, weaknesses persist in enforcement mechanisms (UNDP, 2022; ADB, 2024; OECD, 2023).

In Mongolia, for example, the government's 2019 ban on raw coal was a flagship measure intended to reduce urban winter pollution. However, lower-income households—especially amid the economic impacts of the COVID-19 pandemic—continue to rely on cheaper, polluting fuels such as raw coal and even trash burning due to poverty and limited access to affordable alternatives (Jun, 2021). Public awareness and participation in pollution reduction initiatives also remain limited (Koo et al., 2020; Byambadorj and Lkhaajav, 2025), reducing the social legitimacy and effectiveness of air quality policies. Similar challenges are observed across the CAMCA

region, where urban centers such as Bishkek, Almaty, and Tbilisi experience prolonged winters, high dependence on solid fuels, and insufficient institutional capacity for comprehensive air quality management.

Winter-specific air quality governance is particularly complex because seasonal peaks are driven by essential heating needs, making stringent restrictions politically sensitive and socially challenging. Effective management requires an integrated approach that combines science-based monitoring, targeted fuel transition programs, real-time enforcement, and strong public engagement. In many high-performing cold-climate countries, these measures are embedded within statutory mandates, performance-based regulatory cycles, and transparent governance systems that align environmental, health, and social objectives.

Despite the global recognition of air pollution as a leading environmental health risk, there is a notable lack of comparative, winter-focused governance analysis for the CAMCA context. Existing studies often emphasize technical or fuel-switching interventions but rarely address how legal, institutional, and enforcement frameworks can be adapted to seasonal and socio-economic realities in cold-climate developing regions.

This study addresses that gap by conducting a cross-national benchmarking analysis of air pollution policy implementation across 13 cold-climate countries—including the United States, Canada, Germany, Finland, Poland, China, Korea, and Japan—to identify transferable legal, institutional, and governance practices. Using a mixed-methods approach that integrates legal review, policy evaluation, and governance indicators, the study applies a policy implementation framework to selected CAMCA urban centers to evaluate existing systems and identify reform priorities.

2. LITERATURE REVIEW & CONCEPTUAL FRAMEWORK

The winter air pollution crisis in the Central Asia, Mongolia, and Caucasus (CAMCA) region is driven by persistent reliance on low-quality coal and other solid fuels, combined with weak enforcement capacity and systemic governance gaps (Byambajav et al., 2021; Guttikunda et al., 2023; World Bank, 2025). Regional assessments consistently highlight shortcomings in legal frameworks, institutional coordination, and air quality monitoring systems, all of which limit the effectiveness of pollution control measures (World Bank, 2023).

Effective environmental governance in cold-climate urban contexts requires more than technology adoption—it demands integrated legal frameworks, robust enforcement, affordable access to clean energy technologies, continuous monitoring, and meaningful public participation (Bressers & Kuks, 2004; UNEP, 2023). Multilateral initiatives such as the Central Asia Regional Economic Cooperation (CAREC) Program, the Climate and Clean Air Coalition (CCAC), and the Clean Air for the Northern and Eastern Europe, Caucasus, and Central Asia (CAN-EECCA) network have sought to identify $PM_{2.5}$ hotspots and prioritize interventions. Similarly, UNDP has emphasized the health and economic burdens of air pollution and advocated for cost-effective, integrated policies that actively engage stakeholders (UNDP, 2023).

Empirical studies on Ulaanbaatar and other CAMCA cities confirm the persistence of dangerously high particulate concentrations and associated health harms, reinforcing the urgency of governance reform (Guttikunda et al., 2023; Byambajav et al., 2021). Capacity-building efforts, including the Air Quality Capacity-Building Project (AQCAP), aim to strengthen monitoring capabilities and institutional performance (UNECE, 2025).

However, much of the research and policy support in the region relies heavily on foreign collaboration, with limited focus on **domestic policy formulation and governance reform** in countries such as Mongolia (Soyol-

Erdene et al., 2024). International organizations often prioritize cross-border cooperation and technical assistance, which, while valuable, can overlook structural weaknesses in domestic policy implementation. For example, a 2025 national smog oversight hearing in Mongolia—organized by civil society—exposed significant gaps in public engagement, media coverage, and official responsiveness, underscoring the need for transparent communication and stronger policy accountability (Byambadorj & Lkhaajav, 2025). Mongolian experts remain underrepresented in critical policy discussions, limiting the potential for locally driven reforms despite governance being central to pollution reduction.

Strengthening Mongolia's institutional capacity requires **reforming legal frameworks** to support transparent, evidence-based policymaking that is insulated from political cycles (ADB, 2024). This reform agenda includes integrating emissions reporting into governance systems, linking permits to national net-zero commitments, and opening energy markets to greater competition. Embedding performance-based policy cycles, ensuring consistent stakeholder participation, and fostering professionalized public sector management are widely regarded as prerequisites for sustainable air quality governance (Batbaatar, 2025).

Other CAMCA countries face similar challenges—fragmented institutional mandates, limited inter-agency coordination, and weak accountability—indicating a shared regional need for stronger governance models and cooperative mechanisms to enhance institutional transparency and public trust.

Conceptual Framework:
This study is grounded in governance theory and policy implementation frameworks that emphasize the dynamic interaction between legal mandates, institutional arrangements, and stakeholder participation in environmental governance. Four key dimensions structure the analysis of effective winter air quality governance:

1. **Legal and Regulatory Design** – Clarity of statutory mandates, enforceable standards, and alignment with international best practices to ensure policies are actionable and relevant.
2. **Institutional Capacity and Coordination** – Strong, politically independent environmental authorities with clear mandates, inter-agency collaboration, and sustainable resourcing.
3. **Monitoring and Accountability** – Deployment of real-time, spatially comprehensive monitoring systems paired with transparent data sharing and independent oversight to enable evidence-based decision-making.
4. **Public Engagement and Participation** – Meaningful involvement of local communities, experts, and civil society in policy development, implementation, and compliance monitoring.

This framework guided both the comparative benchmarking of 13 cold-climate countries and the in-depth institutional assessment of CAMCA urban centers, capturing the technical, administrative, and socio-political elements essential for effective air pollution governance.

3. METHODOLOGY

The research employs a mixed-methods approach combining legal and policy document analysis, governance benchmarking, and comparative case studies focused on urban areas within Mongolia, Kazakhstan, Georgia, Kyrgyzstan, and Afghanistan. Drawing on public administration theories—including New Public Management (NPM), New Public Governance (NPG), and Public-Private Partnerships (PPP)—the study examines how institutional roles, coordination mechanisms, and stakeholder engagement influence air quality governance outcomes.

Data sources include peer-reviewed literature, official policy and legislative records, institutional reports, and monitoring data. Special attention is given to analyzing institutional arrangements related to management practices (e.g., performance management, decentralization, autonomy) and enforcement structures.

By explicitly integrating domestic governance dynamics often overlooked in international air pollution research, this approach allows for identifying capacity gaps and tailoring governance recommendations that are practical, adaptive, and contextually appropriate for CAMCA countries.

4. DISCUSSION

4.1 Key Insights from Global Benchmarking

A comparative analysis of 13 cold-climate countries revealed several consistent governance patterns closely linked to measurable improvements in winter air quality:

- **Statutory Mandates with Seasonal Provisions:** Leading countries (e.g., Finland, Japan, Canada) incorporate explicit winter pollution controls into national air quality laws, establishing legally binding seasonal targets and adaptive measures tailored to heating periods.
- **Performance-Based Regulatory Cycles:** Nations such as Germany and Korea implement cyclical policy reviews tied to air quality indicators, allowing for timely mid-course adjustments and the scaling of effective interventions.
- **Integrated Monitoring and Public Transparency:** The U.S., Korea, and Finland employ real-time $PM_{2.5}$ monitoring paired with publicly accessible dashboards, which foster citizen engagement and enhance policy accountability.
- **Economic Incentives for Clean Heating:** Finland, Poland, and Japan use targeted subsidies, tax credits, and low-interest loans to encourage household fuel transitions, effectively reducing reliance on coal and biomass.
- **Enforcement and Compliance Mechanisms:** Canada and Germany maintain independent inspection authorities empowered to issue fines, revoke permits, or mandate corrective actions, ensuring that regulations are effectively enforced rather than merely symbolic.
- **Local Government Empowerment:** Decentralized implementation models, such as Japan's prefectures and Finland's municipalities, facilitate locally tailored solutions aligned with national targets but responsive to specific local conditions.

Collectively, these governance components balance strong central oversight with adaptive, place-based action and inclusive stakeholder engagement. This comprehensive policy architecture underpins the measurable winter air quality improvements observed in these countries.

4.2. CAMCA Region Assessment: Institutional and Governance Challenges

In contrast, the CAMCA region exhibits substantial variation in policy instruments, enforcement effectiveness, and public participation (see Table 1). Kazakhstan and Georgia demonstrate relatively high enforcement rates (~75–80%) and have established transparent public reporting platforms alongside active stakeholder engagement, contributing to improved air quality via strengthened compliance (UNECE, 2020; European Environment Agency [EEA], 2021).

Country	Key Policy Tools	Enforcement Rate	Public Engagement
Mongolia	Winter coal ban, clean stove subsidies	Moderate (~60%)	Public dashboards, limited consultation

Country	Key Policy Tools	Enforcement Rate	Public Engagement
Kazakhstan	Emission limits, industrial fines, subsidies	High (~80%)	NGO involvement, public reporting
Georgia	Ambient standards, clean tech grants	High (~75%)	Stakeholder forums, data transparency
Kyrgyzstan	National standards, vehicle restrictions	Low (~40%)	Community monitoring projects
Afghanistan	Emerging policies, weak enforcement	Low (~30%)	Minimal public participation

Fragmented authority, weak enforcement, limited monitoring, and low public participation undermine effective air quality management, especially in Afghanistan, Kyrgyzstan, and Turkmenistan (World Bank, 2019; UNDP, 2022). Mongolia's enforcement of its coal ban is inconsistent due to poverty and governance challenges (Batbaatar, 2025).

The following synthesis, drawing on policy reports, governance reviews, and academic sources, compares institutional arrangements, stakeholder roles, and collaborative mechanisms across CAMCA countries:

Country	Institutional Arrangements	Stakeholder Roles	Collaborative Mechanisms	Notes / Sources
Mongolia	Centralized governance with multiple agencies; limited coordination between ministries and local governments	Government leads policy; private sector and NGOs involved but limited; low public participation	Emerging multi-stakeholder platforms; weak PPPs; policy enforcement weak	Batbaatar (2025); UNDP (2022); Jun (2021)
Kazakhstan	Relatively strong institutional framework; clear agency mandates with some decentralization	Government agencies highly active; NGOs and industry engaged; better public engagement	Formalized PPPs; transparent reporting platforms; regional cooperation	OECD (2019); UNECE (2020); World Bank (2019)
Georgia	Decentralized governance with local government involvement; national standards exist	NGOs and civil society actively participate; private sector engagement growing	Stakeholder forums and data transparency initiatives	Heinrich Böll Foundation (2022); EEA (2021)
Kyrgyzstan	Fragmented institutional setup; overlapping mandates cause coordination issues	Limited stakeholder engagement; mostly government-led with sporadic community monitoring	Some community-led monitoring projects; weak formal collaboration	ADB (2023); UNDP (2022)
Afghanistan	Weak institutional capacity; unclear roles; fragmented authority	Minimal stakeholder participation; government and NGOs struggle to cooperate	Little to no formal collaboration; low public involvement	Int. Journal of Political Science (2023); UNEP (2018)

This analysis shows Mongolia's governance is highly centralized with limited inter-agency coordination; Kazakhstan benefits from relatively strong, decentralized institutions; Georgia exhibits decentralized governance with active NGO and private sector roles; Kyrgyzstan suffers from overlapping mandates and weak collaboration;

and Afghanistan faces weak institutional capacity with minimal stakeholder engagement (Batbaatar, 2025; OECD, 2019; Heinrich Böll Foundation, 2022; ADB, 2023; UNEP, 2018).

International organizations tend to focus primarily on cross-border environmental issues and technical support, often overlooking the domestic governance dynamics critical for sustainable air pollution control (OECD, 2019; UNDP, 2022).

4.3. Legal Frameworks, Enforcement, Monitoring, and Public Engagement: Standards and Gaps

Best practices emphasize multi-level governance, adaptive regulation, transparency, and active public participation (Sterman, 2000; Meadows, 2008). However, CAMCA countries face challenges including fragmented authority, weak enforcement, outdated standards, and inadequate monitoring infrastructure (World Bank, 2019; UNDP, 2022).

Theoretical Standards & Best Practices	**Current Gaps in CAMCA**	**Explanation and Insights**
Legal & Regulatory Framework	Fragmented authority, overlapping mandates, weak enforcement, inconsistent penalties, lack of accountability and transparent reporting	Fragmented roles delay implementation and reduce effectiveness, especially in Afghanistan, Kyrgyzstan, Turkmenistan. Mongolia shows some progress but enforcement remains inconsistent (Batbaatar, 2025).
Air Quality Standards	Outdated or inconsistently applied; limited coverage of emerging pollutants; lagging behind WHO guidelines	CAMCA standards nominally exist but enforcement and updates are weak; Mongolia's standards trail WHO recommendations, limiting pollution control impact.
Monitoring Infrastructure	Sparse, manual or intermittent monitoring; poor spatial coverage; limited data quality and public transparency	Most countries lack robust, real-time monitoring; Mongolia and Kazakhstan perform better, but lack full transparency, limiting public trust.
Enforcement & Compliance	Low capacity, weak follow-through, limited public engagement; state-controlled energy tariffs inhibit clean energy investments	Weak enforcement and low participation reduce pressure on polluters; dominance of state-owned energy restricts modernization and clean technology uptake.
Policy Integration & Feedback Loops (System Dynamics)	Absent or weak feedback loops; monitoring data rarely inform enforcement; lack of transparent reporting; stakeholder exclusion	Lack of adaptive governance reduces policy impact; Mongolia's recent system dynamics modeling suggests transparency and engagement can improve long-term outcomes.

While Mongolia and Kazakhstan exhibit relatively stronger governance compared to regional peers, institutional and operational weaknesses remain widespread, limiting air quality improvements.

4.4. Implementation of New Public Management (NPM) Mechanisms and Organizational Restructuring

doption of NPM tools and structural reforms varies markedly across CAMCA (see Tables 2 & 3). Mongolia shows limited, uneven implementation; Kazakhstan and Georgia demonstrate more mature, active reforms; Kyrgyzstan and Afghanistan lag considerably, reflecting institutional weakness and scarce research.

Country	Management by Contract	Performance Management	Management by Objectives	Performance Measurement	Research Status
Mongolia	Limited, partial	Gradual, insufficient	Implemented at some levels	Early reforms, no unified system	Understudied (Soyol-Erdene et al., 2024; World Bank, 2019)
Kazakhstan	Some use	Actively used	Implemented	Implemented	Well studied (OECD, 2019; EEA, 2021)
Georgia	Actively implemented	Effectively applied	Actively implemented	Implemented	Well studied (OECD, 2019; EEA, 2021)
Kyrgyzstan	Limited implementation	Limited implementation	Limited implementation	Limited implementation	Understudied (Soyol-Erdene et al., 2024; World Bank, 2019)
Afghanistan	Very limited	Insufficient	Very limited	Very limited	Understudied (UNEP, 2018; Int. Journal of Political Science, 2023)

Weak decentralization and unstable regional agencies hinder local responsiveness and enforcement, exacerbating governance challenges across the region.

Country	Decentralization	Autonomy	Regional Agencies	Devolution	Research Status
Mongolia	Limited	Some agency autonomy	Unstable regional agencies	Limited	Studied in Mongolia and Kyrgyzstan (Soyol-Erdene et al., 2024; ADB, 2023)
Kazakhstan	Partial in regions	Regular practice	Some active agencies	Some devolution	Partial studies
Georgia	Actively implemented	Autonomous agencies	Well-organized regional agencies	Effectively implemented	Well studied
Kyrgyzstan	Limited	Limited	Limited involvement	Very limited	Studied
Afghanistan	Very limited	Limited	Very limited	Very limited	Under-researched

5. CONCLUSION

This study highlights that, beyond the CAMCA region, valuable lessons can be drawn from the governance experiences of the 13 cold-climate countries benchmarked. A key insight is that environmental authorities must operate with political independence and professional autonomy, continuously driving policy development, implementation, and rigorous monitoring. Effective governance requires policies to be introduced in cyclical phases—initially setting achievable standards and then progressively tightening them based on demonstrated

results. Without this adaptive, phased approach, there is a risk of prematurely imposing overly stringent standards disconnected from on-the-ground implementation capacity, rendering policies ineffective and unrealistic.

Moreover, international organizations tend to focus primarily on technical solutions while often overlooking critical aspects of domestic governance, such as institutional roles, mandate clarity, and inter-agency coordination. Since external actors cannot prescribe how internal governance structures should be arranged, it is essential that countries cultivate strong domestic policy institutions. These institutions should actively engage a broad spectrum of national experts, including university professors, researchers, and independent advisors, to foster effective knowledge management and locally relevant policy design.

These lessons from advanced cold-climate nations underscore a shared challenge across CAMCA countries: the absence of unified, integrated frameworks linking research evidence to policy documents and implementation. Many CAMCA countries lack systematic approaches to align policy ambitions with practical enforcement capacity, to implement policies at commensurate levels, and to incrementally raise standards only after prior targets have been met. Addressing these governance gaps is critical for translating international best practices into effective, context-appropriate air quality improvements in the region.

This study reveals critical governance gaps across CAMCA countries, including fragmented institutional mandates, weak enforcement, and limited public participation. Effective winter air quality management requires strengthened institutional autonomy, clear mandate coordination, adaptive and phased policy approaches, and robust stakeholder engagement. Drawing on comparative international experience, this paper emphasizes the necessity of integrated legal frameworks, evidence-driven regulatory cycles, transparent monitoring, and inclusive governance. To translate these insights into practice, a tailored policy benchmarking model and reform roadmap are proposed, focusing on phased implementation, capacity building, and adaptive governance aligned with local socio-economic realities.

6. RECOMMENDATIONS

- **Strengthen Institutional Autonomy and Professionalism**
  Environmental authorities should operate independently from political influence, with clear professional mandates to lead continuous policy development, implementation, and rigorous monitoring.
- **Adopt Adaptive, Phased Policy Approaches**
  Introduce air quality policies in cyclical phases, starting with achievable standards and progressively tightening them based on evidence from implementation outcomes. Avoid setting overly stringent standards prematurely that exceed enforcement capacity.
- **Enhance Domestic Governance Structures**
  Focus on clarifying institutional roles, mandates, and improving inter-agency coordination within countries. Recognize that international actors cannot dictate internal governance arrangements; strong domestic institutions are essential.
- **Engage National Experts and Foster Knowledge Management**
  Integrate diverse national expertise—university professors, researchers, and independent advisors—in policy design and knowledge sharing to ensure locally relevant, evidence-based decisions.
- **Develop Unified, Integrated Frameworks Linking Research and Policy**
  Establish systematic approaches that connect research evidence directly to policy formulation and implementation, aligning ambitions with practical enforcement capacity and allowing incremental policy advancement.

- **Promote Transparent Monitoring and Inclusive Stakeholder Engagement**
  Implement transparent monitoring systems and foster robust public participation to increase accountability and policy legitimacy.
- **Tailor Policy Benchmarking and Reform Roadmaps**
  Design context-specific policy models and phased reform plans that build institutional capacity, support adaptive governance, and reflect local socio-economic and climatic realities in CAMCA urban regions.

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