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Strategic Policy for Strengthening Weather Services Governance through Public–Private Engagement in Indonesia

Kebijakan Strategis untuk Memperkuat Tata Kelola Layanan Cuaca melalui Keterlibatan Publik–Swasta di Indonesia

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Abstract

The rapid digital transformation of meteorological science and the emergence of private weather service providers have significantly reshaped the governance landscape of national weather services. In Indonesia, the absence of standard operating procedures and formal commercial data licensing leaves public-private interactions largely unregulated. This governance gap poses risks to information standardization, creates asymmetric economic value capture, and threatens national atmospheric data sovereignty. Utilizing the USG (Urgency, Seriousness, Growth) matrix to prioritize the core problem and a Fishbone diagram for root-cause analysis, this policy paper examines the regulatory gaps through the theoretical frameworks of collaborative governance and Public-Private Engagement (PPE). The study conducts a comparative evaluation of three regulatory alternatives: a revision of Government Regulation No. 46/2012 to strengthen State Leadership, the enactment of a Presidential Regulation for Strategic Market Expansion, and the enactment of a Presidential Regulation for a Structured PPE model. The evaluation reveals that the Presidential Regulation concerning the Governance of PPE in Value-Added Digital Weather Services is the most optimal solution. Implementing this policy will legally distinguish core public safety services from commercial sectoral services, introduce a transparent licensing framework, and mandate sustainable financial reinvestment mechanisms to ensure the continuous modernization and long-term resilience of Indonesia's national meteorological infrastructure.

Kata Kunci:

Infrastruktur cuaca digital; Kedaulatan data atmosfer; *Public–private engagement* (PPE); Reformasi kebijakan

Abstrak

Transformasi digital yang pesat dalam ilmu meteorologi dan munculnya penyedia layanan cuaca swasta telah secara signifikan mengubah lanskap tata kelola layanan cuaca nasional. Di Indonesia, ketiadaan prosedur operasional standar dan lisensi data komersial formal membuat interaksi publik-swasta sebagian besar tidak teregulasi. Kesenjangan tata kelola ini memicu risiko terhadap standardisasi informasi, menciptakan ketimpangan pengambilan nilai ekonomi, dan mengancam kedaulatan data atmosfer nasional. Dengan menggunakan matriks USG (Urgency, Seriousness, Growth) untuk memprioritaskan masalah utama

Tata kelola layanan cuaca;	*dan diagram Fishbone untuk analisis akar masalah, makalah kebijakan ini mengkaji kesenjangan regulasi melalui kerangka teori collaborative governance dan Public-Private Engagement (PPE). Studi ini melakukan evaluasi komparatif terhadap tiga alternatif regulasi: revisi Peraturan Pemerintah No. 46/2012 untuk memperkuat Kepemimpinan Negara, penetapan Peraturan Presiden untuk Ekspansi Pasar Strategis, dan penetapan Peraturan Presiden untuk Sinergi PPE Terstruktur. Evaluasi komparatif menunjukkan bahwa Peraturan Presiden tentang Tata Kelola PPE dalam Layanan Cuaca Digital Bernilai Tambah adalah solusi yang paling optimal. Implementasi kebijakan ini akan memisahkan secara hukum antara layanan keselamatan publik inti dan layanan sektoral komersial, memperkenalkan kerangka lisensi yang transparan, serta mewajibkan mekanisme reinvestasi finansial yang berkelanjutan untuk menjamin modernisasi dan ketahanan infrastruktur meteorologi nasional Indonesia dalam jangka panjang.*

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INTRODUCTION

Background of the Problem

Weather and climate information constitute a strategic public knowledge infrastructure that plays a fundamental role in safeguarding public safety, supporting economic activities, and strengthening national resilience. Meteorological services play a critical role in disaster risk reduction by enabling early warning systems, hazard monitoring, and risk-informed decision-making. National Meteorological and Hydrological Services (NMHS) provide operational forecasts and climate information that support disaster preparedness and emergency response, particularly in relation to hydrometeorological hazards, such as floods, storms, droughts, and heatwaves. By strengthening hazard monitoring and improving the dissemination of early warnings to authorities and communities, meteorological institutions contribute directly to reducing vulnerability and enhancing societal resilience (Ndah & Odihi, 2017; Street et al., 2018; Tola et al., 2025)

Meteorological information has traditionally been treated as a public good because its benefits are largely non-rivalrous and non-excludable, particularly in the context of early warning systems and disaster risk communication. From an economic perspective, weather and climate information exhibit the classic characteristics of public goods, namely, non-excludability and non-rivalry. Once meteorological information is produced and disseminated, it becomes difficult to exclude individuals from accessing it, and its use by one actor does not reduce its availability to others. Consequently, multiple users can simultaneously benefit from the same forecast without diminishing its value (Georgeson et al., 2017). Consequently, governments have historically maintained primary responsibility for atmospheric observation networks, forecasting systems, and the dissemination of official weather warnings to ensure universal access to critical weather information (Tola et al., 2025).

Public investment in meteorological infrastructure represents a fundamental component of national resilience systems. Atmospheric observations are a primary input for modern weather forecasting, and investments in observation networks and related infrastructure account for a significant share of public expenditures on meteorological services. Determining appropriate levels of investment in observation systems has long been recognized as an important policy challenge, requiring systematic economic evaluation frameworks to assess the societal benefits generated by meteorological observations and forecasting systems (Morss et al., 2005).

However, the governance landscape of weather services is undergoing significant transformation due to rapid technological developments. Advances in high-performance computing, artificial intelligence–based forecasting models, satellite observation technologies, and digital data platforms have improved the accuracy, timeliness, and accessibility of weather information. These developments have also enabled the emergence of private weather service providers offering specialized services such as precision agriculture forecasting, logistics optimization, renewable energy forecasting, financial risk analytics, and parametric insurance modeling.

The rapid development of digital technologies has reshaped weather service ecosystems. Improvements in supercomputing have historically advanced numerical weather prediction through higher spatial resolution and more sophisticated atmospheric simulations. At the same time, emerging technological transitions introduce new organizational and strategic challenges for national meteorological services, potentially altering the traditional structure of the weather-forecasting industry and reshaping the dynamics between public institutions and private actors (Arribas et al., 2020).

Private sector participation in weather-related services has rapidly expanded worldwide. While this expansion can stimulate technological innovation and improve service diversity, it also introduces governance challenges concerning the roles and interactions between public meteorological institutions and private service providers.

Weather and climate information generate substantial economic value by improving decision-making under uncertainty. Forecast information enables governments, businesses, and individuals to anticipate weather conditions, reduce potential losses, and optimize resource allocation (Franzke, 2017). Even imperfect forecasts can produce measurable economic benefits because they enable better decision-making compared to situations in which no weather information is available (Katz & Lazo, 2012). Empirical studies have shown that weather and climate services can improve agricultural productivity, enhance infrastructure planning, reduce disaster-related losses, and strengthen economic resilience across multiple sectors (Freebairn & Zillman, 2002; Vaughan et al., 2017). Recent research has also highlighted the substantial economic value of sector-specific climate services, particularly in agriculture. Agro-meteorological services enable farmers to improve their decision making related to planting schedules, crop management, and climate risk adaptation. Access to reliable weather and climate information can significantly increase agricultural productivity, reduce crop losses, and strengthen resilience to climate shocks (Manzvera & Anaman, 2026).

Beyond the agricultural sector, the systematic provision of meteorological services generates a profound multiplier effect across the broader national economy. The integration of high-resolution weather intelligence into public and private sector operations serves as an indispensable tool for decision-making under uncertainty, enabling actors to optimize resource allocation, enhance infrastructure planning, and significantly reduce disaster-related economic losses. Furthermore, in the context of escalating hydrometeorological hazards driven by climate change, the Sendai Framework for Disaster Risk Reduction explicitly underscores the critical necessity of advanced, integrated early warning systems. By strengthening hazard monitoring and improving the dissemination of these early warnings to both local authorities and vulnerable communities, national meteorological institutions directly mitigate societal vulnerability, shifting the paradigm from reactive emergency response to proactive climate resilience. The economic value derived from these services is substantial, as even imperfect forecasts provide measurable benefits by preventing total operational failures in highly weather-dependent industries.

In emerging digital weather service ecosystems, atmospheric data from publicly funded observation systems serve as the foundational input for many downstream digital services, including mobile weather applications, climate analytics, decision support platforms, and commercial forecasting products. The growing commercialization of weather services raises important policy questions regarding atmospheric data governance, protection of public mandates in early warning services, and the sustainability of national meteorological institutions responsible for maintaining observation infrastructure (Randalls, 2010).

Digital technologies are increasingly shaping governance arrangements in complex environmental systems. Data platforms, artificial intelligence, and digital monitoring systems influence how actors participate in sustainability governance, how knowledge is produced and interpreted, and how decisions are made across institutional boundaries (Kruk et al., 2021). These developments highlight the growing importance of governance frameworks capable of managing digital data ecosystems while ensuring transparency, accountability, and equitable participation.

Without clear governance arrangements, the expansion of weather service providers can create regulatory fragmentation, inconsistent service standards, and confusion over official weather warnings. Commercialization also raises concerns about the equitable use of publicly funded observation infrastructure and atmospheric data sovereignty.

The need to strengthen weather service governance is growing in the context of climate change, as increasing hydrometeorological hazards—such as floods, droughts, extreme rainfall, and tropical storms—require more accurate forecasts and integrated early warning systems.

The Sendai Framework for Disaster Risk Reduction (2015–2030), promoted by the United Nations Office for Disaster Risk Reduction, highlights the importance of early warning systems, climate information, and risk-informed decision-making to reduce disaster losses and strengthen societal resilience (Kelman, 2015).

Globally, the governance of weather services is undergoing rapid transformation. Several countries have increasingly adopted collaborative governance approaches that bring together public institutions, private sector actors, and research organizations in the development of weather services. Collaborative governance emphasizes consensus-oriented decision-making processes and joint problem-solving among multiple stakeholders to address complex policy challenges (Ansell & Gash, 2007).

Collaborative governance has become an increasingly important instrument in public administration for managing complex policy problems involving multiple actors and interests. Effective collaboration requires careful institutional design, trust building among stakeholders, and governance arrangements that ensure legitimacy and accountability (Bjärstig et al., 2024). Legal and institutional frameworks also play a crucial role in enabling collaborative governance by providing the rules and structures necessary to coordinate interactions between public agencies and private actors while safeguarding public values (Amsler, 2016).

Despite growing literature on meteorological modernization and digital forecasting technologies, limited attention has been given to the governance of the expanding digital weather service ecosystem, particularly in developing countries. Most studies focus on technological advancement and forecasting accuracy, while governance structures between public meteorological institutions and private actors remain underexplored, and empirical evidence on socioeconomic benefits remains limited (Suckall & Soares, 2022).

In Indonesia, meteorological services are regulated by Law Number 31 of 2009 on Meteorology, Climatology, and Geophysics, which mandates the state to conduct atmospheric observations, data processing, and information dissemination. This mandate is further implemented through Government Regulation Number 46 of 2012 on the Implementation of Meteorological, Climatological, and Geophysical Services and BMKG Regulation Number 4 of 2022 on Atmospheric Data Access and Cooperation Mechanisms (BMKG, 2012, 2022).

However, the rapid development of digital weather technologies, increasing demand for sector-specific weather services, and expanding participation of private technology actors have revealed several governance gaps that have not yet been fully addressed within existing regulatory arrangements. Therefore, understanding these governance challenges is essential for developing policy frameworks that ensure both innovation and long-term sustainability of national meteorological services in Indonesia.

Identification of Problems

Despite the regulatory frameworks governing meteorological services in Indonesia, several structural challenges remain in the governance of weather services in the digital era. The primary issue is the rapid digital transformation of meteorological science and the massive commercial utilization of atmospheric data by private sector actors require an adaptive governance framework to protect national public safety mandates.

Based on the context above, the resulting problems that require government intervention are identified as follows:

1. The lack of a clear institutional distinction between core public safety services (public goods) and value-added sectoral services (economic goods) (Freebairn & Zillman, 2002; Georgeson et al., 2017)
2. The absence of a structured governance framework to institutionalize Public-Private Engagement (PPE) in the provision of digital weather services (WMO, 2018, 2021)
3. The increasing economic utilization of atmospheric data without mechanisms that link such utilization to sustainable reinvestment in national weather infrastructure (Manzvera & Anaman, 2026; Morss et al., 2005)

The determination of the main problem in this policy paper is conducted using the USG (Urgency, Seriousness, Growth) method, which evaluates each issue based on three key criteria: urgency, referring to how immediately the problem needs to be addressed; seriousness, indicating the extent of its impact on the overall system; and growth, describing how rapidly the problem may worsen if left unaddressed through policy intervention. Based on the assessment results, Problem 2 "The absence of a structured governance framework to institutionalize Public-Private Engagement (PPE) in the provision of digital weather services# is identified as the main problem, as it achieves the highest total score of 15, and therefore becomes the primary focus for in-depth analysis in the subsequent chapters of this policy paper.

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To better understand the underlying drivers of the identified main problem (Problem 2), a structured cause analysis is conducted by distinguishing between Level 1 and Level 2 causes. This approach allows for a systematic examination of both the immediate and deeper factors contributing to the issue.

Cause Analysis (Level 1 and Level 2)

In accordance with the analytical framework for policy development, a Fishbone analysis is utilized to systematically dissect the underlying factors contributing to the established main problem. As illustrated in Figure 1 below, the failure to institutionalize a structured Public-Private Engagement (PPE) governance framework for digital weather services is not an isolated issue, but rather the culmination of intersecting challenges across four primary dimensions: Regulatory Gaps, Data Governance, Bureaucratic Structure, and Legal Oversight. This visual mapping serves to precisely identify the fundamental root causes such as the absence of standard operating procedures and formal licensing frameworks that require targeted policy intervention.

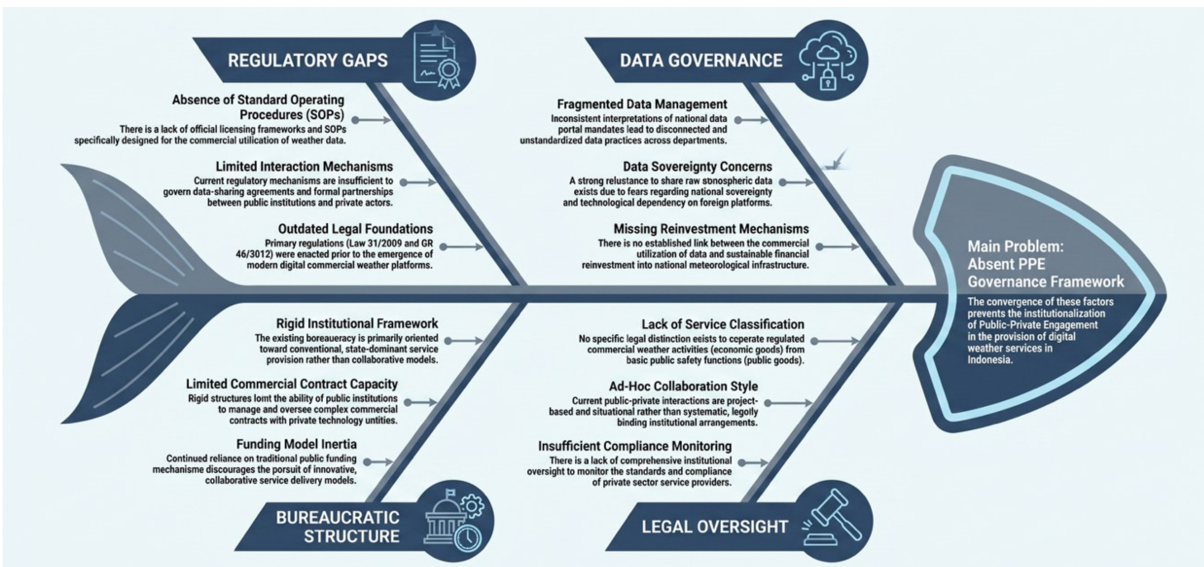

Figure 1. Root Cause Analysis of the Absent PPE Governance Framework

To determine the priority problem to be solved by the policy, an assessment using the USG (Urgency, Seriousness, Growth) matrix is conducted as shown in Table 1.

Table 1. Assessment of the Problem Using the USG (Urgency, Seriousness, Growth) Method

List of Problems	U	S	G	Total Score	Rank
Problem 1: The lack of a clear institutional distinction between core public safety services (public goods) and value-added sectoral services (economic goods)	4	4	4	12	2
Problem 2: The absence of a structured governance framework to institutionalize Public-Private Engagement (PPE) in the provision of digital weather services	5	5	5	15	1
Problem 3: The increasing economic utilization of atmospheric data without mechanisms that link such utilization to sustainable reinvestment in national weather infrastructure	3	4	3	10	3

Research Problem

The absence of standard operating procedures and formal licensing frameworks for commercial weather data utilization leads to unregulated interactions and data-sharing between public institutions and private actors, thereby preventing the establishment of a structured governance framework for Public-Private Engagement (PPE) in digital weather services in Indonesia.

Research Objectives

The primary objective of this policy paper is to formulate a robust and adaptive governance architecture capable of managing the expanding digital weather service ecosystem in Indonesia. Specifically, this study aims to:

1. Identify and systematically analyze the root causes of the governance gaps preventing structured interactions between public meteorological institutions and private technology actors.
2. Evaluate the adequacy of the existing national regulatory frameworks, specifically Law Number 31 of 2009 and Government Regulation Number 46 of 2012, in responding to the rapid commercialization of atmospheric data.
3. Conduct a rigorous comparative evaluation of three distinct governance models—the State-Dominant Model, the Market-Driven Model, and the Structured Public-Private Engagement (PPE) Model—using nine specialized criteria.
4. Propose a concrete, actionable policy recommendation to institutionalize a structured PPE framework that safeguards national data sovereignty while establishing sustainable financial reinvestment mechanisms for meteorological infrastructure.

Research Contributions

This study provides significant practical and strategic contributions to policymakers, specifically the Agency for Meteorology, Climatology, and Geophysics (BMKG) and the Ministry of National Development Planning (Bappenas). Practically, this paper delivers a definitive policy roadmap for drafting a Presidential Regulation (or comprehensively revising Government Regulation No. 46/2012) to legally classify weather services and establish standardized commercial licensing. Strategically, the study contributes a viable financial blueprint by demonstrating how structured data utilization frameworks can mitigate the state's fiscal burden by legally requiring commercial actors to reinvest in national observation networks and computational infrastructure. Ultimately, this research assists the government in transforming ad-hoc public-private collaborations into a highly structured, mutually beneficial ecosystem.

THEORITICAL AND CONSEPTUAL FRAMEWORK

Theoretical Framework

To systematically analyse the established problem statement this section applies relevant theoretical perspectives alongside an assessment of the existing regulatory landscape. The objective is to employ these frameworks as analytical tools to identify practical and actionable policy alternatives that can foster a more collaborative and innovative digital weather ecosystem.

The governance of weather and climate services is closely related to broader discussions on public goods, environmental data governance, and collaborative institutional arrangements. Understanding these theoretical perspectives is essential for analysing the evolving roles of public institutions and private actors in the provision of meteorological information (Amsler, 2016; Douglas & Ansell, 2020; WMO, 2015, 2021) .

From an economic perspective, weather information has long been categorized as a public good because it exhibits the characteristics of non-rivalry and non-excludability. In the context of meteorological services, early warning systems, public weather forecasts, and disaster risk communication are examples of services that must remain universally accessible because they directly affect public safety and societal welfare (Freebairn & Zillman, 2002; Georgeson et al., 2017; Tola et al., 2025). Consequently, governments have traditionally assumed primary responsibility for developing and operating meteorological infrastructure, including observation networks, forecasting systems, and warning dissemination mechanisms (Katz & Lazo, 2012).

However, technological advancements have significantly expanded the potential use of atmospheric data beyond public safety functions. The integration of high-performance computing, artificial intelligence, satellite observations, and digital data platforms has enabled the generation of highly specialized weather products tailored for sectors such as energy, transportation, agriculture, finance, and insurance (Arribas et al., 2020; Street et al., 2018; WMO, 2021). These developments have gradually transformed atmospheric data into a valuable economic resource that can support a wide range of commercial applications (Georgeson et al., 2017; Troccoli, 2018).

This transformation has led to the emergence of new governance challenges. While core weather services continue to function as public goods, many sector-specific weather services increasingly exhibit the characteristics of economic or quasi-commercial services, in which additional value is generated through advanced data processing and analytical services (Freebairn & Zillman, 2002; Suckall & Soares, 2022; Troccoli, 2018). Consequently, the traditional governance model, in which national meteorological institutions act as the sole providers of weather services, has become increasingly complex. The growing ecosystem of private weather service providers requires new institutional arrangements that can accommodate innovation while maintaining the integrity of public safety services (WMO, 2018, 2022).

In response to these developments, scholars and policymakers have increasingly emphasized the importance of collaborative governance in managing complex public service systems (Amsler, 2016; Bjärstig et al., 2024; Douglas & Ansell, 2020). Collaborative governance refers to institutional arrangements in which public institutions, private sector actors, and other stakeholders jointly participate in decision-making and service provision processes. Such arrangements allow governments to leverage technological innovation and investment from the private sector while retaining regulatory oversight and ensuring that public interests are protected.

This shift towards collaborative governance represents a critical departure from traditional, "one-size-fits-all" approaches in public sector management, which have increasingly proven insufficient for managing highly complex, technology-driven policy environments. Effective collaborative governance is not merely an administrative delegation of duties; rather, it requires meticulous institutional design, the systematic building of trust among diverse stakeholders, and robust governance architectures that guarantee both democratic legitimacy and public accountability. To fully optimize this framework, policymakers must open the "black box" of public administration, transitioning from rigid bureaucratic control toward adaptive, interpretive governance models that recognize the distinct operational cultures of private technology firms. By doing so, the state can establish legally binding rules and structures that seamlessly coordinate interactions between public agencies and commercial entities, thereby safeguarding fundamental public values while stimulating continuous technological entrepreneurship.

Within this context, the concept of public–private engagement (PPE) has gained increasing relevance in sectors where public infrastructure generates both public and commercial value (WMO, 2018, 2022). PPE differs from traditional public–private partnerships in that it emphasizes institutional coordination, transparency, and shared responsibilities rather than purely contractual relationships (WMO, 2022). Through structured engagement mechanisms, governments can facilitate private sector participation in value-added services while ensuring that core public mandates, such as safety warnings, data integrity, and universal access, remain fully protected (WMO, 2022).

Another important concept in this discussion is environmental data governance, which highlights the strategic importance of data generated through publicly funded observational systems. Environmental data infrastructure, including atmospheric observation networks and forecasting systems, represents long-term national investments that support scientific research, economic decision-making, and disaster risk management (Fernández-Miguel et al., 2025; Kruk et al., 2021; Morss et al., 2005) Effective governance of such infrastructure requires clear institutional arrangements regarding data access, utilization, and reinvestment mechanisms to ensure long-term sustainability (Kruk et al., 2021; Layode et al., 2024).

These theoretical perspectives provide a foundation for analyzing how national weather services can adapt to technological transformation while maintaining their core public mandate. In particular, they highlight the need for governance models that clearly distinguish between public safety services and value-added sectoral services while enabling structured collaboration between public institutions and private actors (Amsler, 2016; Ansell & Gash, 2007; WMO, 2022).

Conceptual Framework

Based on the theoretical perspectives discussed above, the governance of weather services in the digital era can be conceptualized as an interaction between public mandates, technological transformation, and growing sectoral demand for specialized weather services (Arribas et al., 2020; Georgeson et al., 2017; WMO, 2015, 2021). Ensuring the reliability and integrity of these services requires strong institutional governance, sustained investment in meteorological infrastructure, and clear regulatory oversight (BMKG, 2012; Georgeson et al., 2017; Street et al., 2018).

Rapid technological development has expanded the potential application of atmospheric data across multiple economic sectors. Industries such as renewable energy, logistics, agriculture, aviation, and financial services increasingly rely on high-resolution weather information and predictive analytics to improve operational efficiency and manage climate-related risks (Street et al., 2018). This growing sectoral demand creates opportunities for the development of specialized weather services that extend beyond the scope of traditional public weather forecasts.

The interaction between these two dynamics creates a governance challenge: how to enable innovation and private sector participation in value-added weather services while safeguarding the public mandate of national meteorological institutions. Without clear institutional arrangements, the coexistence of public and private weather service providers may result in fragmented information systems, regulatory uncertainty, and an unequal distribution of economic value derived from publicly funded atmospheric data (WMO, 2018, 2022).

To address this challenge, this study conceptualizes structured public–private engagement as a governance mechanism capable of balancing public authority, technological innovation, and sectoral service expansion (Douglas & Ansell, 2020; WMO, 2022). Under this framework, weather services are classified into two broad categories: core public safety and sector-specific value-added services. The core services remain under the authority of public meteorological institutions to ensure reliability, standardization, and universal accessibility. Private actors may also participate in developing sectoral services that generate additional economic value through advanced data processing and application-specific solutions.

A key element of this framework is the establishment of transparent institutional mechanisms that link the economic utilization of atmospheric data to sustainable reinvestment in national weather infrastructure. Such mechanisms ensure that the benefits generated from specialized weather services contribute to the long-term sustainability of observation networks, computational infrastructure, and forecasting capabilities (Manzvera & Anaman, 2026).

Through this conceptual framework, the governance of weather services is positioned not only as a technical issue but also as a strategic policy challenge involving institutional coordination, technological innovation, and sustainable financing. Therefore, the framework provides an analytical basis for evaluating policy alternatives and formulating recommendations to strengthen the governance of national weather services in Indonesia.

METHODOLOGY

This policy paper employs a structured policy analysis methodology that integrates qualitative regulatory assessment with quantitative scoring techniques. The analytical process is systematically conducted through three primary phases:

1. Problem Prioritization using the USG Method: To determine the core governance issue requiring immediate policy intervention, this study applies the USG (Urgency, Seriousness, Growth) matrix. Each identified problem is systematically evaluated based on three parameters: *Urgency* (how pressing the issue is), *Seriousness* (the magnitude of its impact on the national meteorological system), and *Growth* (the rate at which the problem will worsen if left unaddressed). This method provides an objective, quantified basis for prioritizing the absence of a PPE framework as the central research problem.
2. Root Cause Analysis via Fishbone Diagram: Following the identification of the main problem, a Fishbone diagram is utilized to systematically dissect its underlying drivers. This analytical tool maps the immediate and fundamental root causes across four structural dimensions: Regulatory Gaps, Data Governance, Bureaucratic Structure, and Legal Oversight, ensuring a comprehensive diagnosis of the institutional failures.
3. Comparative Policy Evaluation: To determine the most optimal policy solution, a comparative evaluation matrix is employed. Three alternative governance models are formulated and assessed against nine specialized criteria tailored to the digital weather

ecosystem. Utilizing an expert panel assessment simulation, each alternative is scored on a scale of 1 to 10 across all dimensions. The qualitative justification for these scores is derived from an extensive document analysis of national regulations (Law No. 31/2009 and GR No. 46/2012) , World Meteorological Organization (WMO) guidelines, and collaborative governance literature.

RESULT AND DISCUSSION

The analysis of regulatory frameworks and institutional arrangements revealed several key findings regarding the governance of weather services in Indonesia. These findings relate primarily to the institutional structure of meteorological service provision, the evolving role of atmospheric data in the digital economy, and emerging challenges associated with the rapid expansion of weather information applications.

First, the regulatory framework governing meteorological services in Indonesia establishes a strong mandate for the state to manage atmospheric observations, forecasting, and the dissemination of official weather information. Law Number 31 of 2009 concerning Meteorology, Climatology, and Geophysics assigns the government responsibility for conducting atmospheric observation activities, processing meteorological data, and providing weather information to the public. This regulatory framework emphasizes the role of meteorological services in supporting disaster risk reduction, public safety, aviation operations, and maritime navigation.

Second, institutional analysis indicates that the national meteorological system has developed an extensive infrastructure for atmospheric observation and forecasting. These infrastructures include surface observation networks, satellite data assimilation systems, numerical weather prediction models, and early warning dissemination mechanisms. Such infrastructure forms the backbone of national meteorological services and enables the delivery of reliable weather information to the public (Freebairn & Zillman, 2002; WMO, 2021).

Technological developments have expanded the use of atmospheric data beyond traditional forecasting. Advances in artificial intelligence and digital platforms enable specialized weather services for sectors such as agriculture, energy, logistics, aviation, and finance. These changes have created a broader weather service ecosystem where public meteorological institutions interact with private companies, and atmospheric information functions both as a public safety resource and an input for economic productivity and climate risk management (WMO, 2018).

The findings indicate that the current governance framework remains primarily oriented toward public weather service provision. Existing regulations emphasize the state's responsibility for maintaining observation infrastructure and delivering official forecasts, while governance mechanisms regulating interactions with private weather service providers remain limited.

Another key finding is the growing importance of meteorological infrastructure as a strategic national asset. As the economic value of weather information increases, stronger governance mechanisms for atmospheric data utilization are needed.

Analysis of Current Regulation and Policies

Indonesia possesses a robust and strategic institutional foundation for the provision of meteorological services, which serves as a primary pillar for national safety and resilience.

Law Number 31 of 2009 concerning Meteorology, Climatology, and Geophysics establishes an essential state mandate to conduct atmospheric observations, process data, and provide authoritative weather information to protect all layers of society. While this legal instrument has proven highly effective in executing core functions such as disaster risk reduction, aviation operations, and maritime navigation, there is a strategic opportunity to modernize the regulatory framework to better accommodate the rapid advancement of digital weather platforms (BMKG, 2009) . This solid legal foundation can be further optimized to legitimize the creation of a classification system that clearly distinguishes the state's fundamental safety functions from sectoral activities, thereby safely integrating the innovative capabilities of the private sector.

In alignment with this foundational mandate, Government Regulation Number 46 of 2012 concerning the Implementation of Meteorological, Climatological, and Geophysical Services successfully details the operational execution of these services. Current policy analysis identifies a significant opportunity to strengthen this regulation by establishing explicit standard operating procedures for atmospheric data sharing between public institutions and private entities (BMKG, 2012).

The urgency to modernize these regulations is further amplified by the ongoing digitalization of environmental governance. Digital platforms, algorithmic forecasting, and artificial intelligence now heavily influence how stakeholders participate in sustainability governance and how critical environmental data is interpreted across institutional boundaries. However, the existing regulatory framework, having been drafted prior to the proliferation of these digital data ecosystems, lacks specific provisions to manage the massive commercialization of raw atmospheric data. This legislative void inadvertently creates data privacy and security challenges, as the unmonitored extraction and utilization of national atmospheric data by foreign or private platforms may compromise sensitive public information and lead to technological dependency. Therefore, elevating the current regulatory framework is not merely an administrative upgrade; it is a vital safeguard to ensure transparent, accountable, and secure data governance that comprehensively protects national data sovereignty in a rapidly expanding digital ecosystem.

By enhancing this regulatory framework, the government can eliminate operational ambiguity and formally separate core safety services which serve as universal public goods from value added sectoral services that function as economic goods. This progressive distinction will foster a more transparent, standardized, and mutually beneficial pathway for public-private interactions.

At the technical and institutional level, BMKG Regulation Number 4 of 2022 concerning Atmospheric Data Access and Cooperation Mechanisms reflects a highly progressive and positive initial step toward opening broader spaces for external collaboration. This regulation holds immense potential to be elevated from a framework that manages situational, project-based collaborations into a comprehensive, legally binding licensing and royalty structure (BMKG, 2022). Such a policy transformation will empower the state to effectively manage and capture the economic value generated by the commercial utilization of atmospheric data by private technology companies. Ultimately, this strategic enhancement will support sustainable reinvestment mechanisms, ensuring the long-term independence, resilience, and modernization of the national weather infrastructure.

Synthesis for Policy Alternatives

The synthesis of theoretical frameworks and regulatory analysis highlights Indonesia's significant potential to optimize its meteorological ecosystem. While the country benefits from a strong institutional foundation for meteorological services, the rapid expansion of digital weather applications has introduced new governance challenges that require adaptive and forward-looking policy responses.

Although existing regulations provide a solid foundation for public safety, they remain largely state-centric and are not fully equipped to accommodate the growing role of private actors. Bridging this gap will require the development of structured operational procedures for commercial data licensing, as well as clear financial reinvestment mechanisms.

Accordingly, to support both technological innovation and the long-term sustainability of national meteorological services, this analysis serves as a basis for evaluating a range of viable policy alternatives.

Research Limitations

This study acknowledges certain contextual and methodological limitations. First, the scope is restricted to the governance, legal, and economic architecture of weather services, deliberately excluding technical evaluations of private forecasting algorithms or computational mechanics. Second, the comparative policy evaluation relies primarily on synthesized literature and qualitative regulatory analysis rather than primary empirical data collected directly from private sector stakeholders, highlighting an area for future empirical research. Finally, the analysis is strictly confined to Indonesia's national regulatory framework and the central mandate of BMKG, meaning findings may require adaptation before application in decentralized or regional contexts.

Research Novelty and Contributions

The novelty of this study lies in its definitive shift away from the traditional technocentric discourse of meteorology toward the complex institutional governance of environmental data. While the majority of existing literature concentrates on advancements in forecasting accuracy and high-performance computing, this paper originally addresses the critical "governance void" created by these technological leaps within a developing country context.

Furthermore, this study introduces a highly original conceptualization of the World Meteorological Organization's Public-Private Engagement (PPE) guidelines specifically tailored to Indonesia's legal landscape. It uniquely highlights the imminent threats of "asymmetric value capture" and "information fragmentation" as central policy problems. By proposing a legally binding mechanism that directly links the commercialization of atmospheric data by private tech entities to the sustainable financial reinvestment in public observation networks, this study pioneers a modern governance architecture that treats digital weather data simultaneously as a sovereign public asset and a catalyst for economic innovation.

ALTERNATIVES POLICIES

The governance transformation of weather services in the digital era requires more than incremental administrative adjustments. Advances in digital technologies, data platforms, and artificial intelligence have reshaped the institutional landscape of meteorological services and created new governance challenges for national institutions (Arribas et al., 2020; Kruk et al., 2021). These pressures arise from three key developments: the expansion of digital weather technologies, the growing economic utilization of atmospheric data, and the need to preserve the public mandate of meteorological institutions in safeguarding public safety.

Weather and climate information have become strategic resources for both public safety and economic decision-making. Sectors such as agriculture, transportation, renewable energy, insurance, and logistics increasingly rely on weather intelligence to manage climate risks and improve operational efficiency (Vaughan et al., 2017). At the same time, meteorological information retains the characteristics of a public good, particularly in early warning systems and disaster risk communication.

Therefore, the key policy question is not whether governance reform is necessary, but which institutional arrangement is most appropriate for managing the interaction between public authority, technological innovation, and sectoral demand for weather services. To address this issue, this study identifies three policy alternatives: the state-dominant model, the open-market model, and the structured public–private engagement model, each reflecting different assumptions about the role of the state, atmospheric data governance, and the institutional architecture of weather services.

Alternative Policy 1: Revision of Government Regulation Number 46 of 2012 to Strengthen State Leadership in Meteorological Services

The first alternative proposes a revision of Government Regulation (GR) Number 46 of 2012 to reinforce the state's role as the primary steward of meteorological services. Under this regulatory instrument, the national meteorological institution (BMKG) retains its position as the principal provider of both core public safety warnings and specialized sectoral services, maintaining comprehensive oversight of all observation networks and forecasting systems. This approach is highly effective in ensuring the maximum protection of the public safety mandate through centralized and standardized coordination of weather information.

The main strength of this model is the strong protection of public mandates. By centralizing strategic functions within a public institution, the state can preserve the authority of official weather information, minimize fragmentation of warning systems, and maintain control over atmospheric data as a sovereign public asset (Georgeson et al., 2017; Katz & Lazo, 2012).

The state-dominant model also reduces ambiguity in institutional responsibility. Public accountability remains within the national meteorological authority, minimizing confusion between official warnings and private weather products—an important factor in high-risk sectors such as disaster early warning, aviation, and maritime operations.

However, sustaining this model requires substantial and continuous public investment to keep pace with rapid global technological advancements. While this approach is exceptionally strong in preserving information integrity and national data sovereignty, it may encounter challenges in maintaining the operational agility required to rapidly adopt emerging digital technologies if it relies exclusively on state budgetary capacities.

Alternative Policy 2: Enactment of a Presidential Regulation on Strategic Market Expansion and the Optimization of Atmospheric Data Access

The second alternative entails the enactment of a new Presidential Regulation designed to encourage active, independent participation from the private sector. In this model, the state focuses on providing and maintaining foundational observation infrastructure, while the private sector is granted broad opportunities to develop and commercialize value-added weather services. This policy approach aims to strongly stimulate technological innovation, attract private investment, and expand service diversity for highly productive industrial sectors.

Although it offers a dynamic environment for innovation, this approach requires meticulous regulatory oversight to prevent the dissemination of unstandardized or inconsistent weather information to the public. Furthermore, it necessitates carefully calibrated policies to ensure that the commercial utilization of publicly funded data yields an equitable economic return, thereby supporting the continuous maintenance and modernization of the national data infrastructure.

Alternative Policy 3: Enactment of a Presidential Regulation concerning the Governance of Public-Private Engagement (PPE) in Value-Added Digital Weather Services

The third and recommended alternative is the enactment of a Presidential Regulation to institutionalize a structured Public-Private Engagement (PPE) synergy model. This regulation is explicitly designed to harmonize the government's strategic role in ensuring public safety with the innovative capacity of the private sector through clearly delineated responsibilities. Under this model, the state retains absolute authority over core public safety services, while the private sector serves as a strategic partner in developing value-added sectoral applications guided by a transparent licensing framework.

The primary strength of this approach is its remarkable ability to secure national data sovereignty while simultaneously establishing a clear, legally sound pathway for technological innovation. Crucially, this regulation institutionalizes a financial sustainability mechanism wherein commercial users of atmospheric data contribute directly to the reinvestment in national meteorological infrastructure. This ensures that the modernization of digital weather technologies proceeds sustainably and delivers equitable economic benefits to all stakeholders within the ecosystem.

Comparative Evaluation of Policy Alternatives

This study conducted a comparative policy evaluation to assess the strengths and limitations of alternative governance models for weather services. The evaluation used governance criteria derived from the literature on collaborative governance and public service delivery, reflecting the interaction of public safety mandates, technological innovation, and the economic utilization of atmospheric data in digital weather ecosystems.

The criteria include protection of public safety mandates, innovation and technological development, economic value creation, institutional coordination, data governance and sovereignty, financial sustainability, service diversity and sectoral application, information standardization, and implementation feasibility in developing country contexts. The comparative evaluation is summarized in table 2.

Table 2. Comparative Policy Evaluation Matrix for Governance Models in the Digital Weather Service Ecosystem

Evaluation Criteria	Alternative 1: Revision of GR 46/2012 (State Leadership)	Alternative 2: Presidential Regulation (Market Expansion)	Alternative 3: Presidential Regulation (Structured PPE)
Protection of Public Safety Mandate	Highly effective through centralized control and official warning authority.	Requires robust oversight to ensure trust in official warnings is maintained.	Highly effective by securing state authority while enabling complementary private services.
Innovation and Technological Development	Steady progress, though heavily reliant on state investment capacity.	Exceptionally high potential driven by market competition and tech entrepreneurship.	Exceptionally high by synergizing public infrastructure with private technological agility.
Economic Value Creation	Steady, though primarily focused on core public services rather than commercial markets.	High potential through extensive commercialization across multiple industries.	High and sustainable, preserving public infrastructure ownership while expanding markets.
Institutional Coordination and Governance Stability	Exceptionally clear due to centralized authority.	Requires strong coordination mechanisms to align independent private actors.	Structured governance mechanisms facilitate collaboration between meteorological institutions, private service providers, and research organizations.
Data Sovereignty and Data Governance	Strong protection of national atmospheric data sovereignty due to centralized data management. However, restricted access may limit innovation.	Data governance may become fragmented if private actors rely on multiple data sources with varying standards and proprietary platforms.	Establishes clear data access policies and governance frameworks that balance openness, innovation, and the protection of national data sovereignty.
Financial Sustainability of Meteorological Institutions	Heavy reliance on government funding may limit long-term financial sustainability under fiscal constraints.	Private companies capture economic value from meteorological data, whereas public institutions continue to bear infrastructure costs.	It enables sustainable financing through collaborative mechanisms, regulated data utilization frameworks, and reinvestment in

Evaluation Criteria	Alternative 1: Revision of GR 46/2012 (State Leadership)	Alternative 2: Presidential Regulation (Market Expansion)	Alternative 3: Presidential Regulation (Structured PPE)
			meteorological infrastructure.
Service Diversity and Sectoral Applications	Service diversification remains limited because public institutions prioritize core forecasting and warning functions.	High diversity of specialized weather services tailored to various industries	It enables diversified sectoral applications while maintaining institutional oversight and service quality standards.
Information Standarization	Excellent standardization; official information remains singular and centralized.	Requires proactive regulatory measures to align diverse and inconsistent weather information communication channels.	Excellent standardization achieved through regulatory oversight of private providers.
Implementation Feasibility in Developing Countries	Feasible, where institutional authority is strong but may constrain technological advancement and investment capacity.	Challenging without prior establishment of comprehensive market regulations.	Highly feasible, offering a pragmatic balance of public authority and private innovation.

Source: Author's analysis.

The superior performance of the Structured Public-Private Engagement (PPE) Model is intrinsically linked to its capacity to harmonize the often-competing dynamics of public authority and private market incentives. This model strategically leverages governmental mandates for public safety and data sovereignty while integrating the agility and innovation of the private sector to foster a robust and diversified digital weather service ecosystem (Frei, 2021). This synergistic approach ensures that essential public services, such as early warning systems, are maintained and enhanced, while simultaneously catalyzing economic value creation through specialized meteorological applications (Street et al., 2018). This collaboration addresses critical needs in climate resilience by fostering an environment where data governance is robust, ensuring the integrity and ethical use of vast datasets, and promoting collaborative research and development (Anthony, 2025). Furthermore, this integrated governance framework facilitates a market for climate services that balances public interest with private sector innovation, thereby supporting the broader objectives of net-zero energy transitions and enhanced societal resilience against climate variability (Intergovernmental Panel on Climate Change (IPCC), 2023; Troccoli et al., 2024)

By deliberately classifying core meteorological services as non-excludable public goods and sector-specific applications as value-added economic goods, this model completely eradicates the regulatory ambiguity that currently stifles institutional coordination. Furthermore, the model provides an unparalleled advantage in achieving the long-term financial sustainability of national meteorological institutions.

Instead of public institutions bearing the continuous, heavy fiscal burden of infrastructure maintenance while private entities unilaterally extract economic value, the structured PPE model institutionalizes sustainable financing mechanisms. Through meticulously regulated data utilization frameworks, commercial actors are legally required to contribute to the reinvestment in the national observation networks and computational infrastructure. This ensures that the modernization of the digital weather service ecosystem remains highly feasible and economically sustainable, particularly within the fiscal constraints often experienced by developing countries. This structured approach cultivates a robust Global Weather Enterprise where public, private, and academic sectors cooperate for mutual benefit, ensuring continuous improvement in accuracy and reliability of weather information and services (Weller et al., 2019). Such a framework would incentivize global producing centers to share their comprehensive suite of services with low-income countries, thereby generating significant global socioeconomic benefits (Kull et al., 2016). This framework aligns with broader initiatives, such as the Global Framework for Climate Services, which aims to expand access to climate data and information and build national capacities for managing climate risks and opportunities. This strategic alignment fosters an environment where the provision of both intellectual and digital infrastructure resources, along with quality-controlled data, is governed through a sustainable public-private partnership framework (Bauer, 2024).

To objectively evaluate and determine the most optimal governance solution, a comprehensive comparative policy evaluation is conducted using the exact, uncombined criteria derived directly from the digital weather service ecosystem analysis. These nine distinct criteria encompass the Protection of Public Safety Mandate, Innovation and Technological Development, Economic Value Creation, Institutional Governance Coordination and Governance Stability, Data Sovereignty and Data Governance, Financial Sustainability of Meteorological Institutions, Service Diversity and Sectoral Applications, the mitigation capability regarding the Risk of Information Fragmentation, and Implementation Feasibility in Developing Countries. To quantify this comparative evaluation in accordance with standard policy analysis methodologies, an expert panel assessment is utilized to score each alternative on a scale of 1 to 10 across all nine dimensions. For consistency in scoring where a higher number indicates a more positive outcome, the risk of information fragmentation is evaluated based on the model's capacity to successfully mitigate and prevent such risks.

Table 3. Policy Alternatives Scoring

Policy Alternatives	Alternative 1: Revision of GR 46/2012 (State Leadership)	Alternative 2: Presidential Regulation (Market Expansion)	Alternative 3: Presidential Regulation (Structured PPE)
C1: Protection of Public Safety Mandate	9	3	9
C2: Innovation and Technological Development	4	9	9
C3: Economic Value Creation	4	9	9
C4: Institutional Governance Coordination and Governance Stability	7	3	8
C5: Data Sovereignty and Data Governance	8	3	9
C6: Financial Sustainability of Meteorological Institutions	4	3	9
C7: Service Diversity and Sectoral Applications	4	9	9
C8: Information Standarization	9	3	8
C9: Implementation Feasibility in Developing Countries	7	3	8

Policy Alternatives	Alternative 1: Revision of GR 46/2012 (State Leadership)	Alternative 2: Presidential Regulation (Market Expansion)	Alternative 3: Presidential Regulation (Structured PPE)
Total Score	56	45	78

Source: Author's analysis.

Table 3 shows the systematic evaluation of these three alternatives utilizes the comprehensive criteria established in the initial policy study, ensuring a rigorous and multidimensional assessment of the digital weather ecosystem. Alternative 1: Revision of GR 46/2012 (State Leadership) achieves a highly commendable score in safeguarding the public safety mandate, ensuring robust national atmospheric data sovereignty, and effectively mitigating the risk of information fragmentation through centralized control. However, its overall score is substantially constrained by limitations in driving rapid technological development, generating economic value, and securing independent financial sustainability due to an absolute reliance on government funding and rigid bureaucratic processes.

Conversely, the Alternative 2: Presidential Regulation (Market Expansion) excels remarkably in accelerating innovation, creating economic value, and expanding service diversity and sectoral applications through vigorous market competition and private investment. Despite these progressive strengths, it receives the lowest cumulative score because the severe vulnerabilities regarding fragmented information, compromised institutional governance stability, and inequitable financial burdens make it an unfeasible approach for managing critical national environmental data.

Alternative 3: Presidential Regulation (Structured PPE) elegantly emerges as the highest-scoring and most optimal policy solution by harmoniously integrating public infrastructure stewardship with private innovation capacity. By brilliantly distinguishing core public services from value-added applications, this model secures exceptionally high scores across all evaluated dimensions. It effectively preserves the ultimate authority of national meteorological institutions in issuing official forecasts while establishing transparent data governance policies that balance openness with uncompromised national data sovereignty. Furthermore, it guarantees robust financial sustainability through regulated data utilization frameworks that generate direct reinvestment into the meteorological infrastructure, making it a highly pragmatic, balanced, and implementable governance architecture. Based on this rigorous comparative evaluation, the Structured Public-Private Engagement Model definitively resolves the established problem statement and serves as the robust foundation for the actionable policy recommendation presented in the subsequent chapter.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The rapid digital transformation of meteorological science and the expanding ecosystem of private weather service providers have fundamentally reshaped the governance landscape of national weather services. While public meteorological institutions remain absolutely essential for safeguarding public safety and maintaining strategic environmental data infrastructure, the escalating demand for high-resolution, sector-specific weather applications necessitates a structured collaboration with non-state actors. As established through the preceding analysis, the prevailing lack of standard operating procedures and formal licensing frameworks for commercial data utilization has left these public-private interactions largely unregulated. This governance gap not only creates severe risks of information fragmentation and asymmetric economic value capture, but it also poses a critical threat to national atmospheric data sovereignty, leaving immense economic potential untapped.

Through a rigorous, multi-dimensional comparative policy evaluation, this paper definitively identifies the Structured Public-Private Engagement (PPE) Model as the most optimal and balanced governance architecture. Moving beyond the limitations of both the rigid state-dominant approach and the vulnerable open-market model, the Structured PPE framework elegantly harmonizes the state's public safety mandate with the innovative agility of the private sector. It successfully achieves this balance by formally classifying weather services into non-excludable public goods—such as core early warning systems—and value-added economic goods tailored for commercial sectoral applications.

Ultimately, operationalizing this collaborative model transforms national meteorological governance from a situational, ad-hoc arrangement into a highly regulated and synergistic ecosystem. By instituting legally binding data-sharing protocols and mandatory financial reinvestment mechanisms, the state can secure the continuous, independent funding required to modernize national observation networks and computational infrastructure. Consequently, the implementation of the Structured PPE Model ensures that Indonesia's digital weather infrastructure systematically evolves into a strategically protected public asset, driving continuous technological innovation, enhancing societal climate resilience, and securing national competitiveness within the global digital economy.

Policy Recommendation

To effectively operationalize the Structured Public-Private Engagement model and decisively resolve the governance gap, the singular recommended policy intervention is the formulation and enactment of a Presidential Regulation concerning the Governance of Public-Private Engagement in the Provision of Value-Added Digital Weather Services. Alternatively, this can be achieved through a comprehensive revision of Government Regulation Number 46 of 2012 to explicitly incorporate commercial data licensing and collaborative governance mechanisms.

This strategic policy is directly addressed to the Head of the Agency for Meteorology, Climatology, and Geophysics acting as the primary leading sector, in close coordination with the Ministry of Finance and the Ministry of National Development Planning to ensure seamless fiscal and institutional alignment.

The enactment of this regulation requires the execution of several concrete administrative steps to guarantee its successful implementation. Initially, the regulation must formally mandate a clear institutional classification of weather services, unequivocally distinguishing core public meteorological services dedicated to early warning and disaster risk communication from value-added sectoral services tailored for commercial industries. Following this classification, the regulation must establish a standardized, legally binding licensing framework that dictates the terms of commercial data access, utilization, and sharing between public institutions and private technology companies. This framework will provide absolute legal certainty for private investments while uncompromisingly protecting national atmospheric data sovereignty.

Furthermore, the policy must institutionalize a sustainable financial mechanism that directly links the economic and commercial utilization of weather information by private actors to the continuous reinvestment in national observation networks, forecasting systems, and digital data infrastructure. By executing these concrete regulatory steps, the government will successfully transform ad-hoc collaborations into a highly structured, transparent, and mutually beneficial ecosystem. Ultimately, the implementation of this specific policy recommendation will strengthen Indonesia's meteorological governance, ensuring that weather services sustainably support public safety, accelerate technological innovation, and drive continuous economic development.

REFERENCES

Amsler, L. B. (2016). Collaborative Governance: Integrating Management, Politics, and Law. *Public Administration Review*, *76*(5), 700–711. https://doi.org/10.1111/puar.12605

Ansell, C., & Gash, A. (2007). Collaborative Governance in Theory and Practice. *Journal of Public Administration Research and Theory*, *18*(4), 543–571. https://doi.org/10.1093/jopart/mum032

Anthony, F. (2025). Leveraging Artificial Intelligence for Smarter Climate Policy and Strategic Government Planning. *Journal of Sustainable Development*, *18*, 77. https://doi.org/10.5539/jsd.v18n6p77

Arribas, A., Robinson, N. H., & Evans, P. A. (2020). What is next for National Meteorological Services? *ArXiv (Cornell University)*. https://doi.org/10.48550/arxiv.2005.01425

Bauer, P. (2024). What if? Numerical weather prediction at the crossroads. *Journal of the European Meteorological Society*, *1*, 100002. https://doi.org/10.1016/j.jemets.2024.100002

Bjärstig, T., Johansson, J., Mancheva, I., & Sandström, C. (2024). Collaboration as a policy instrument in public administration: Evidence from forest policy and governance. *Environmental Policy and Governance*, *34*(5), 538–549. https://doi.org/10.1002/eet.2099

BMKG. (2009). *Law of the Republic of Indonesia Number 31 of 2009 on Meteorology, Climatology and Geophysics* .

BMKG. (2012). *Peraturan Pemerintah Nomor 46 Tahun 2012 tentang Penyelenggaraan Pengamatan dan Pengolahan Data Meteorologi, Klimatologi, dan Geofisika*. Sekretariat Negara.

BMKG. (2022). *Peraturan Badan Meteorologi, Klimatologi, dan Geofisika Nomor 4 Tahun 2022 tentang Kebijakan Pengaksesan Data di Lingkungan BMKG*. Badan Meteorologi, Klimatologi, dan Geofisika.

Douglas, S., & Ansell, C. (2020). Getting a Grip on the Performance of Collaborations: Examining Collaborative Performance Regimes and Collaborative Performance Summits. *Public Administration Review*, *81*(5), 951–961. https://doi.org/10.1111/puar.13341

Fernández-Miguel, A., García-Muiña, F. E., Riccardi, M. P., Veglio, V., & Settembre-Blundo, D. (2025). Strategic and Systemic Sustainability: Redefining EU Governance Beyond Environmental Policy. *Sustainability*, *17*(18), 8208. https://doi.org/10.3390/su17188208

Franzke, C. L. E. (2017). Impacts of a Changing Climate on Economic Damages and Insurance. *Economics of Disasters and Climate Change*, *1*(1), 95–110. https://doi.org/10.1007/s41885-017-0004-3

Freebairn, J., & Zillman, J. W. (2002). Economic benefits of meteorological services. *Meteorological Applications*, *9*(1), 33–44. https://doi.org/10.1017/s1350482702001044

Frei, T. (2021). Public–private engagement (PPE) in hydromet services and the role of the academic sector. *Meteorological Applications*, *28*(5). https://doi.org/10.1002/met.2025

Georgeson, L., Maslin, M., & Poessinouw, M. (2017). Global disparity in the supply of commercial weather and climate information services. *Science Advances*, *3*(5). https://doi.org/10.1126/sciadv.1602632

Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change Information for Regional Impact and for Risk Assessment. In *Climate Change 2021 – The Physical Science Basis* (pp. 1767–1926). Cambridge University Press. https://doi.org/10.1017/9781009157896.014

Katz, R. W., & Lazo, J. K. (2012). Economic Value of Weather and Climate Forecasts. In *Oxford University Press eBooks* (pp. 559–584). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780195398649.013.0021

Kelman, I. (2015). Climate Change and the Sendai Framework for Disaster Risk Reduction. *International Journal of Disaster Risk Science*, *6*(2), 117–127. https://doi.org/10.1007/s13753-015-0046-5

Kruk, S. R. L., Kloppenburg, S., Toonen, H., & Bush, S. R. (2021). Digitalizing environmental governance for smallholder participation in food systems. *Earth System Governance*, *10*, 100125. https://doi.org/10.1016/j.esg.2021.100125

Kull, D., Graessle, C., & Aryan, B. (2016). *Strengthening National Hydrometeorological Services through Cascading Forecasting Investing for Sustainability and Impact across Global, Regional, and National Centers*. http://econ.worldbank.org.

Layode, O., Naiho, H. N. N., Adeleke, G. S., Udeh, E. O., & Labake, T. T. (2024). Data privacy and security challenges in environmental research: Approaches to safeguarding sensitive information. *International Journal of Applied Research in Social Sciences*, *6*(6), 1193–1214. https://doi.org/10.51594/ijarss.v6i6.1210

Manzvera, J., & Anaman, K. A. (2026). Economic value of agro-meteorological services: a review of the international literature. *Frontiers in Climate*, *8*. https://doi.org/10.3389/fclim.2026.1741828

Morss, R. E., Miller, K. A., & Vasil, M. S. (2005). A Systematic Economic Approach to Evaluating Public Investment in Observations for Weather Forecasting. *Monthly Weather Review*, *133*(2), 374–388. https://doi.org/10.1175/mwr-2857.1

Ndah, A. B., & Odihi, J. O. (2017). A Systematic Study of Disaster Risk in Brunei Darussalam and Options for Vulnerability-Based Disaster Risk Reduction. *International Journal of Disaster Risk Science*, *8*(2), 208–223. https://doi.org/10.1007/s13753-017-0125-x

Randalls, S. (2010). Weather profits: Weather derivatives and the commercialization of meteorology. *Social Studies of Science*, *40*(5), 705–730. https://doi.org/10.1177/0306312710378448

Street, R., Buontempo, C., Myšiak, J., Karali, E., Pulquério, M., Murray, V., & Swart, R. (2018). How could climate services support disaster risk reduction in the 21st century. *International Journal of Disaster Risk Reduction*, *34*, 28–33. https://doi.org/10.1016/j.ijdrr.2018.12.001

Suckall, N., & Soares, M. B. (2022). Evaluating the benefits of weather and climate services in South Asia: a systematic review. *Regional Environmental Change*, *22*(3). https://doi.org/10.1007/s10113-022-01947-7

Tola, F. T., Dadi, D. K., Kenea, T. T., & Dinku, T. (2025). Weather and climate services in Ethiopia: progress, challenges, and opportunities. *Frontiers in Climate*, *7*. https://doi.org/10.3389/fclim.2025.1551188

Troccoli, A. (2018). *Achieving Valuable Weather and Climate Services* (pp. 13–25). https://doi.org/10.1007/978-3-319-68418-5_2

Troccoli, A., Fuchs, T., Boscolo, R., Matt, E., & Bastani, H. (2024). Coproduction of Integrated Weather and Climate Services to Support Net-Zero Energy Transitions. *Bulletin of the American Meteorological Society*, *105*(8), E1569–E1583. https://doi.org/10.1175/BAMS-D-23-0029.1

Vaughan, C., Dessai, S., Hewitt, C., Baethgen, W., Terra, R., & Berterretche, M. (2017). Creating an enabling environment for investment in climate services: The case of Uruguay's National Agricultural Information System. *Climate Services*, *8*, 62–71. https://doi.org/10.1016/j.cliser.2017.11.001

Weller, R. A., Baker, D. J., Glackin, M. M., Roberts, S. J., Schmitt, R. W., Twigg, E. S., & Vimont, D. J. (2019). The Challenge of Sustaining Ocean Observations. *Frontiers in Marine Science*, *Volume 6-2019*. https://doi.org/10.3389/fmars.2019.00105

WMO. (2015). *WMO policy on the international exchange of meteorological and related data and products*. World Meteorological Organization.

WMO. (2018). *Summary of the WMO questionnaire on the status of public–private engagement in WMO members*. World Meteorological Organization.

WMO. (2021). *WMO unified data policy*. World Meteorological Organization.

WMO. (2022). *Public–private engagement (PPE) policies, guidelines, and publications*. World Meteorological Organization.