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Regulating Autonomous Systems for Sustainable Resource Use: Insights from Interviews with Environmental Law Experts

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ABSTRACT

The rapid integration of autonomous systems powered by artificial intelligence (AI) into environmental governance has created both unprecedented opportunities and complex regulatory challenges for sustainable resource use. This study examines how autonomous systems influence environmental decision-making and evaluates the adequacy of existing regulatory frameworks in addressing their environmental impacts. Using a qualitative research design based on secondary data and synthesised insights from environmental law experts, the study identifies key governance gaps, including regulatory fragmentation, lack of environmental accountability, and the absence of lifecycle sustainability assessments. Drawing on an integrated theoretical framework that combines socio-technical systems theory, environmental governance theory, responsible AI principles, and sustainability theory, the research proposes a multidimensional regulatory approach. The findings highlight the need to incorporate environmental law principles, particularly the precautionary and polluter pays principles, into AI governance frameworks. The study concludes that effective regulation requires multilevel governance, enhanced transparency, and enforceable environmental standards. By bridging the gap between environmental law and AI governance, this research contributes to the emerging discourse on sustainable and responsible deployment of autonomous systems.

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1. Introduction

The rapid advancement of autonomous systems driven by artificial intelligence (AI) has fundamentally reshaped the landscape of environmental governance and sustainable resource management. Autonomous systems, defined as technologies capable of performing tasks and making decisions with minimal or no human intervention, are increasingly being deployed in areas such as climate monitoring, precision agriculture, water resource management, biodiversity conservation, and energy optimisation. These systems rely on machine learning algorithms, big data analytics, and sensor-based networks to process vast amounts of environmental data in real time, thereby enabling more efficient and informed decision-making processes (Henderson et al., 2020).

The integration of autonomous systems into environmental governance has created new opportunities for achieving sustainability goals. For instance, AI-powered tools can optimise irrigation systems, reduce water waste, predict natural disasters, and monitor deforestation with unprecedented accuracy. In the context of global climate change, such technologies play a crucial role in advancing the objectives of the United Nations Sustainable Development Goals (SDGs), particularly those related to climate action, clean water, and sustainable ecosystems (United Nations, 2020). By enhancing predictive capabilities and enabling adaptive management strategies, autonomous systems contribute to more efficient resource allocation and improved environmental outcomes.

However, the growing reliance on autonomous systems also raises significant concerns regarding their environmental and regulatory implications. While these technologies are often promoted as tools for sustainability, they are themselves associated with substantial environmental costs. The development and operation of AI systems require significant computational resources, leading to increased energy consumption and carbon emissions. Studies have shown that training large-scale machine learning models can generate emissions comparable to those of entire industries, thereby contributing to environmental degradation rather than mitigating it (Strubell et al., 2019). This paradox highlights the need for a critical examination of the sustainability claims associated with autonomous systems.

In addition to environmental concerns, the deployment of autonomous systems introduces complex legal and governance challenges. Traditional environmental law frameworks are not fully equipped to address the unique characteristics of AI-driven technologies. Environmental law has historically been based on principles such as prevention, precaution, and the polluter pays doctrine, which assume clear causal relationships between actions and environmental harm (De Sadeleer, 2021). However, autonomous systems operate in dynamic and often opaque ways, making it difficult to attribute responsibility for environmental impacts. The lack of transparency in algorithmic decision-making, often referred to as the “black box” problem, further complicates issues of accountability and regulatory oversight (Jobin et al., 2019).

Moreover, existing AI governance frameworks tend to focus primarily on ethical considerations such as fairness, bias, and human rights, while paying relatively little attention to environmental sustainability. Although organisations such as the OECD and the European Commission have developed guidelines for responsible AI, these frameworks often lack enforceable provisions for assessing and mitigating environmental impacts (OECD, 2022; European Commission, 2021). As a result, there is a growing recognition of the need to integrate environmental considerations into AI governance to ensure that technological innovation aligns with sustainability objectives.

Another critical challenge lies in the fragmented nature of regulatory approaches across different jurisdictions. Autonomous systems are deployed globally, yet regulatory frameworks vary significantly between countries and regions. This lack of harmonisation creates regulatory gaps and inconsistencies, making it difficult to establish comprehensive standards for environmental accountability. Furthermore, the transboundary nature of environmental issues, such as climate change and biodiversity loss, necessitates coordinated international action, which is currently lacking in the context of AI governance (Batool et al., 2025).

Against this backdrop, environmental law experts have increasingly called for the adoption of precautionary and adaptive regulatory approaches to address the uncertainties associated with autonomous systems. The precautionary principle, in

particular, provides a valuable framework for managing risks in situations where scientific knowledge is incomplete or uncertain. By emphasising proactive measures to prevent environmental harm, this principle can help guide the responsible deployment of autonomous technologies (Trouwborst, 2009). At the same time, adaptive governance mechanisms are needed to ensure that regulatory frameworks remain flexible and responsive to technological advancements.

This study seeks to address these challenges by examining the regulatory implications of autonomous systems for sustainable resource use. Specifically, it aims to explore how environmental law principles can be integrated with AI governance frameworks to develop a comprehensive regulatory approach. Drawing on qualitative analysis of secondary data and synthesised insights from environmental law experts, the study identifies key regulatory gaps and proposes strategies for enhancing environmental accountability in the deployment of autonomous systems.

The research is guided by four key questions: How do autonomous systems impact sustainable resource use? What regulatory gaps exist in governing these systems? How can environmental law principles be effectively integrated with AI governance frameworks? And what insights can be derived from environmental law experts regarding regulatory reform? By addressing these questions, the study contributes to the emerging field of environmental AI governance and provides a foundation for future research and policy development.

2. Literature Review

The role of autonomous systems in environmental governance has expanded significantly in recent years, driven by advances in machine learning, data analytics, and sensor technologies. These systems are increasingly used to monitor environmental conditions, predict ecological changes, and support decision-making processes. For example, AI-based models are used to forecast climate patterns, detect illegal deforestation, and optimise energy consumption in smart grids (Henderson et al., 2020).

The integration of autonomous systems into environmental governance represents a shift from traditional, human-centred decision-making to algorithmically mediated processes. This shift has important implications for how environmental risks are assessed and managed. According to Ali et al. (2026), algorithmic systems are not merely tools but active participants in governance processes, shaping the interpretation of environmental data and influencing policy outcomes. This transformation raises questions about the legitimacy and accountability of algorithmic decision-making in environmental contexts.

2.1 Environmental Impacts of AI and Autonomous Systems

While autonomous systems offer significant benefits for environmental management, they also have substantial environmental footprints. The energy consumption associated with training and deploying AI models is a major concern. Data centres, which support AI operations, require large

amounts of electricity and water for cooling, contributing to greenhouse gas emissions and resource depletion (Strubell et al., 2019).

In addition to energy consumption, the production of hardware components for AI systems involves the extraction of rare earth minerals and other resources, which can have negative environmental impacts. The disposal of electronic waste further exacerbates these issues. As a result, there is growing recognition of the need to consider the full lifecycle environmental impacts of autonomous systems, from production and operation to disposal (Lucivero, 2024).

Despite these concerns, environmental considerations are often overlooked in AI governance frameworks. Most existing guidelines focus on ethical and social issues, with limited attention to environmental sustainability. This gap highlights the need for more comprehensive approaches that integrate environmental and technological considerations.

2.2 AI Governance Frameworks and Principles

AI governance frameworks aim to ensure the responsible development and deployment of AI technologies. These frameworks are typically based on principles such as transparency, accountability, fairness, and human oversight. Jobin et al. (2019) identified a global convergence around these principles, although their implementation varies across different contexts.

The OECD (2022) and the European Commission (2021) have developed influential AI governance frameworks that emphasise trustworthiness and human-

centric design. However, these frameworks often lack specific provisions for addressing environmental impacts. For example, while they call for risk assessment and impact evaluation, they do not mandate environmental audits or sustainability reporting.

Batool et al. (2025) argue that effective AI governance requires a multilevel approach that involves coordination between governments, industry, and civil society. Such an approach is particularly important in the context of environmental governance, where multiple stakeholders are involved.

2.3 Environmental Law Principles and Their Relevance

Environmental law provides a well-established framework for regulating activities that impact the environment. Key principles include:

- **Precautionary Principle:** Advocates for preventive action in the face of uncertainty (Trouwborst, 2009).
- **Prevention Principle:** Emphasises avoiding environmental harm before it occurs.
- **Polluter Pays Principle:** Assigns responsibility for environmental damage to those who cause it.
- **Sustainable Development:** Balances environmental, social, and economic objectives (De Sadeleer, 2021).

These principles are highly relevant for regulating autonomous systems, as they provide normative guidelines for managing environmental risks. However, their

application to AI technologies is not straightforward. The complexity and opacity of autonomous systems make it difficult to identify causal relationships and assign responsibility for environmental harm.

2.4 Regulatory Gaps and Challenges

The literature identifies several key regulatory gaps in the governance of autonomous systems:

- **Lack of Environmental Accountability:** Many organisations do not disclose the environmental impacts of their AI systems, and there are no standardised requirements for sustainability reporting (Lucivero, 2024).
- **Absence of Lifecycle Assessments:** Current frameworks do not require comprehensive assessments of environmental impacts across the entire lifecycle of AI systems.
- **Fragmented Governance:** Regulatory approaches vary across jurisdictions, leading to inconsistencies and gaps in enforcement (Batool et al., 2025).
- **Limited Integration of Environmental and AI Governance:** Environmental law and AI governance operate largely in parallel, with limited interaction between the two domains.
- **Challenges of Accountability:** The autonomous nature of AI systems complicates the attribution of responsibility for environmental harm.

2.5 Emerging Approaches and Future Directions

Recent studies have proposed various approaches to address these challenges. One promising approach is the integration of environmental impact assessments into AI governance frameworks. This would involve evaluating the environmental implications of AI systems at different stages of their lifecycle.

Another approach is the adoption of adaptive governance mechanisms that can respond to technological changes. Adaptive governance emphasises flexibility, learning, and stakeholder participation, making it well-suited for managing the uncertainties associated with autonomous systems.

Furthermore, there is growing interest in developing international standards for AI governance that incorporate environmental considerations. Such standards could help harmonise regulatory approaches and promote global cooperation.

3. Theoretical Framework

The regulation of autonomous systems for sustainable resource use requires a multidimensional theoretical foundation that captures the complex interactions between technology, law, governance, and environmental sustainability. This study adopts an integrated theoretical framework that combines socio-technical systems theory, environmental governance theory, responsible AI principles, and sustainability theory. Together, these perspectives provide a comprehensive lens for understanding how autonomous systems operate within

environmental contexts and how they can be effectively regulated.

3.1 Socio-Technical Systems Theory

Socio-technical systems theory conceptualises technology as embedded within a broader network of social, institutional, and environmental relationships. Rather than viewing autonomous systems as isolated tools, this perspective emphasises their interaction with human actors, regulatory institutions, and ecological systems (Bijker et al., 2012). Autonomous systems are shaped by design choices, organisational practices, and policy environments, while simultaneously influencing decision-making processes and environmental outcomes.

In the context of environmental governance, socio-technical systems theory highlights the co-evolution of technology and regulatory frameworks. For example, the deployment of AI-driven monitoring systems in environmental management not only enhances data collection but also reshapes governance structures by redistributing decision-making authority. This shift raises important questions about accountability, transparency, and legitimacy, particularly when decisions are made by opaque algorithmic systems (Ali et al., 2026). By situating autonomous systems within a socio-technical context, this theory provides a foundation for analysing the broader implications of technological innovation.

3.2 Environmental Governance Theory

Environmental governance theory focuses on the institutional arrangements and processes

through which environmental resources are managed. It emphasises the role of multiple actors, including governments, private sector organisations, non-governmental organisations, and local communities, in shaping environmental outcomes (Lemos & Agrawal, 2006). Governance is understood as a multilevel and polycentric system, where decision-making occurs across local, national, and international scales.

This perspective is particularly relevant for regulating autonomous systems, which operate across jurisdictional boundaries and involve diverse stakeholders. Environmental governance theory underscores the importance of coordination and collaboration in addressing complex environmental challenges. For instance, the regulation of AI-driven resource management systems requires alignment between national policies, international agreements, and industry standards (Batool et al., 2025).

Furthermore, environmental governance theory highlights the need for participatory approaches that incorporate stakeholder input into decision-making processes. In the context of autonomous systems, this implies the inclusion of affected communities in the design and implementation of AI technologies. Such participation enhances legitimacy and ensures that technological solutions align with local environmental and social priorities.

3.3 Responsible AI Framework

The responsible AI framework provides a set of normative principles for the ethical development and deployment of AI technologies. Key principles include

transparency, accountability, fairness, and human oversight (Jobin et al., 2019). These principles are widely recognised in global AI governance initiatives, such as those developed by the OECD (2022) and the European Commission (2021).

In the context of environmental governance, the responsible AI framework must be extended to include environmental considerations. While existing guidelines emphasise ethical and social impacts, they often overlook the environmental footprint of AI systems. Integrating environmental sustainability into responsible AI requires the incorporation of additional principles, such as energy efficiency, resource conservation, and lifecycle environmental assessment (Lucivero, 2024).

Transparency is particularly important for addressing the “black box” nature of autonomous systems. Without access to information about how decisions are made, it is difficult to assess the environmental impacts of these systems or hold developers accountable. Similarly, accountability mechanisms must be adapted to address the distributed and autonomous nature of AI systems, where responsibility may be shared among multiple actors.

3.4 Sustainability Theory

Sustainability theory provides an overarching framework for evaluating the long-term impacts of autonomous systems on environmental, social, and economic systems. The concept of sustainable development, as defined by the Brundtland Commission, emphasises the need to meet present needs without compromising the

ability of future generations to meet their own needs (United Nations, 2020).

In the context of autonomous systems, sustainability theory highlights the importance of balancing technological innovation with environmental protection. While AI technologies can enhance resource efficiency, their environmental costs must also be considered. This includes not only direct impacts, such as energy consumption, but also indirect impacts, such as resource extraction and electronic waste (Strubell et al., 2019).

Sustainability theory also emphasises the need for systemic thinking, recognising that environmental challenges are interconnected and cannot be addressed in isolation. This perspective supports the integration of environmental law principles with AI governance frameworks to ensure that autonomous systems contribute to sustainable outcomes.

3.5 Integrated Conceptual Model

Based on the above theoretical perspectives, this study proposes an integrated conceptual model for regulating autonomous systems in environmental contexts. In this model:

- **Socio-technical systems theory** provides the contextual foundation, highlighting the interaction between technology and society.
- **Environmental governance theory** defines the institutional and multilevel governance structures.
- **Responsible AI principles** ensure ethical and operational accountability.

- **Sustainability theory** serves as the overarching objective guiding regulatory efforts.

The integration of these theories enables a holistic understanding of the challenges and opportunities associated with autonomous systems. It also provides a basis for developing regulatory frameworks that are both effective and adaptable to technological change.

4. Methodology

This study adopts a qualitative research design to explore the regulatory implications of autonomous systems for sustainable resource use. Qualitative research is particularly well-suited for examining complex and emerging phenomena, where existing knowledge is limited and contextual understanding is essential (Creswell & Poth, 2018). The study employs a secondary data analysis approach, drawing on existing literature, policy documents, and expert insights to generate new interpretations and theoretical contributions.

The research design is exploratory and interpretive, aiming to identify patterns, themes, and relationships within the data. By synthesising diverse sources of information, the study provides a comprehensive understanding of the regulatory landscape and the challenges associated with governing autonomous systems.

4.1 Data Sources

The study relies on multiple sources of secondary data to ensure a robust and

comprehensive analysis. These sources include:

- **Peer-reviewed academic literature:** Articles from journals in environmental law, AI governance, and sustainability studies provide theoretical and empirical insights.
- **Policy documents and regulatory frameworks:** Reports and guidelines from organisations such as the OECD, European Commission, and United Nations offer information on current governance approaches.
- **Legal texts and environmental law principles:** Foundational legal doctrines and principles are used to analyse regulatory frameworks.
- **Synthesised expert interviews:** Insights from environmental law experts are derived from published interviews, panel discussions, and expert commentaries.

The use of multiple data sources enhances the validity and reliability of the findings through triangulation (Yin, 2018).

4.2 Data Collection Process

The data collection process involved a systematic review of relevant literature and documents. Sources were selected based on their relevance to the research questions and their contribution to understanding the intersection of autonomous systems, environmental governance, and regulation.

Search strategies included the use of academic databases such as Google Scholar, Scopus, and Web of Science, with keywords such as “autonomous systems,” “AI governance,” “environmental law,” and

“sustainability.” Policy documents were obtained from official organisational websites.

In addition, expert insights were collected from publicly available sources, including conference proceedings, webinars, and published interviews. These sources provide valuable perspectives on practical challenges and policy implications.

4.3 Data Analysis Method

The study employs thematic analysis as the primary method for analysing qualitative data. Thematic analysis involves identifying, analysing, and interpreting patterns or themes within the data (Braun & Clarke, 2006). This method is widely used in qualitative research due to its flexibility and applicability to diverse data sources.

The analysis followed a six-step process:

- **Familiarisation with the data:** Reviewing and organising the collected materials.
- **Generating initial codes:** Identifying key concepts and categories related to regulation, sustainability, and AI governance.
- **Searching for themes:** Grouping codes into broader themes, such as accountability, transparency, and environmental impact.
- **Reviewing themes:** Refining and validating themes to ensure coherence and relevance.
- **Defining and naming themes:** Clearly articulating the meaning and scope of each theme.

- **Producing the report:** Integrating themes into a coherent narrative.

4.4 Reliability and Validity

To ensure the rigour of the research, several strategies were employed:

- **Triangulation:** Using multiple data sources to validate findings (Yin, 2018).
- **Transparency:** Clearly documenting the research process and analytical steps.
- **Theoretical grounding:** Anchoring the analysis in established theoretical frameworks.
- **Critical evaluation:** Assessing the credibility and relevance of sources.

These measures enhance the trustworthiness of the study and support the validity of its conclusions (Mannan & Farhana, 2026).

4.5 Limitations of the Study

Despite its contributions, the study has certain limitations. The reliance on secondary data may limit the depth of insights compared to primary data collection. Additionally, the synthesis of expert interviews may not fully capture the diversity of perspectives in the field. Future research could address these limitations by conducting primary interviews and empirical case studies.

5. Findings and Analysis

The qualitative analysis of secondary data and synthesised expert insights reveals a complex and evolving landscape in the regulation of autonomous systems for sustainable resource use. The findings are

organised into six major thematic areas: the dual role of autonomous systems in environmental governance, environmental externalities of AI systems, regulatory fragmentation, accountability deficits, lifecycle sustainability gaps, and emerging regulatory innovations.

5.1 Autonomous Systems as Transformative Environmental Governance Tools

Autonomous systems have emerged as transformative instruments in environmental governance by enabling real-time monitoring, predictive analytics, and automated decision-making. These technologies are widely applied in climate modelling, biodiversity monitoring, precision agriculture, and water resource management. For instance, AI-driven satellite systems can detect deforestation patterns and illegal mining activities with unprecedented accuracy, thereby enhancing enforcement capabilities (Henderson et al., 2020).

From a governance perspective, these systems facilitate a shift from reactive to proactive environmental management. Predictive algorithms allow policymakers to anticipate environmental risks and implement preventive measures, aligning with the prevention principle in environmental law (De Sadeleer, 2021). Moreover, autonomous systems can optimise resource allocation by identifying inefficiencies and suggesting adaptive strategies, thereby contributing to sustainable development goals.

However, the findings indicate that these benefits are accompanied by significant governance challenges. Autonomous systems are not neutral tools; they actively shape environmental decision-making processes by influencing data interpretation and policy priorities (Ali et al., 2026). This raises concerns about the epistemic authority of algorithms and the potential marginalisation of human judgment. Experts emphasise that reliance on algorithmic systems may lead to “automation bias,” where decision-makers over-trust machine outputs, potentially resulting in suboptimal or harmful environmental outcomes.

5.2 Environmental Externalities of Autonomous Systems

A critical finding of this study is the paradoxical environmental impact of autonomous systems. While these technologies are often promoted as solutions for sustainability, they also generate significant environmental externalities. The energy consumption associated with training and operating AI models is particularly concerning. Large-scale machine learning systems require extensive computational resources, leading to increased electricity usage and carbon emissions (Strubell et al., 2019).

Data centres, which support AI operations, are major contributors to environmental degradation due to their high energy and water demands. In addition, the production of hardware components for AI systems involves the extraction of rare earth minerals, which can result in habitat destruction and pollution. The disposal of electronic waste

further exacerbates these environmental impacts (Lucivero, 2024).

Experts highlight that these externalities are often overlooked in policy discussions, leading to an incomplete assessment of the sustainability of autonomous systems. The lack of transparency in reporting environmental impacts further complicates the issue. As a result, there is a growing need for comprehensive environmental assessments that consider the full lifecycle of AI systems.

5.3 Regulatory Fragmentation and Governance Gaps

The analysis reveals significant fragmentation in the regulatory landscape governing autonomous systems. Existing frameworks are dispersed across different domains, including environmental law, data protection, and AI ethics, with limited coordination between them. This fragmentation creates gaps and inconsistencies in regulatory oversight, undermining the effectiveness of governance efforts (Batoool et al., 2025).

At the international level, there is no unified framework for regulating autonomous systems in environmental contexts. While organisations such as the OECD and the European Commission have developed guidelines for AI governance, these frameworks are largely non-binding and lack enforcement mechanisms (OECD, 2022; European Commission, 2021). National regulations also vary widely, reflecting different policy priorities and levels of technological development.

Experts emphasise that the transboundary nature of environmental issues, such as climate change and biodiversity loss, necessitates coordinated international action. However, the absence of harmonised standards and enforcement mechanisms poses significant challenges for global governance. This regulatory fragmentation not only limits the effectiveness of environmental protection measures but also creates uncertainty for stakeholders.

5.4 Accountability Deficits in Autonomous Systems

One of the most significant challenges identified in this study is the lack of accountability in the deployment of autonomous systems. Traditional environmental law frameworks rely on clear causal relationships between actions and environmental harm, enabling the attribution of responsibility. However, the autonomous and complex nature of AI systems complicates this process.

Autonomous systems often operate as “black boxes,” making it difficult to understand how decisions are made. This lack of transparency hinders the ability to assess environmental impacts and assign responsibility for harm (Jobin et al., 2019). Furthermore, the distributed nature of AI development and deployment means that multiple actors, including developers, operators, and users, may share responsibility, creating ambiguity in accountability.

Experts argue that existing liability frameworks are insufficient for addressing these challenges. There is a need for new legal approaches that account for the unique

characteristics of autonomous systems. These may include strict liability regimes, shared responsibility models, and the incorporation of accountability mechanisms into system design.

5.5 Lifecycle Sustainability Gaps

Another key finding is the absence of comprehensive lifecycle assessments for autonomous systems. Current regulatory frameworks tend to focus on the operational phase of AI systems, neglecting the environmental impacts associated with their production and disposal. This narrow focus results in an incomplete understanding of the sustainability of these technologies.

Lifecycle assessments are essential for evaluating the environmental footprint of autonomous systems, including energy consumption, carbon emissions, resource use, and waste generation. Experts emphasise that such assessments should be integrated into regulatory frameworks to ensure that sustainability considerations are addressed at all stages of the system lifecycle (Lucivero, 2024).

The lack of standardised methodologies for conducting lifecycle assessments further complicates this issue. Without consistent metrics and reporting requirements, it is difficult to compare the environmental impacts of different systems or to establish benchmarks for sustainability.

5.6 Emerging Regulatory Innovations

Despite the challenges identified above, the study also highlights emerging regulatory innovations aimed at addressing the

environmental impacts of autonomous systems. These include the integration of environmental impact assessments into AI governance frameworks, the development of sustainability standards for AI systems, and the adoption of adaptive governance mechanisms.

The precautionary principle is increasingly being recognised as a valuable tool for regulating autonomous systems in the face of uncertainty. By emphasising preventive action, this principle can help mitigate potential environmental risks associated with emerging technologies (Trouwborst, 2009). Additionally, adaptive governance approaches, which emphasise flexibility and learning, are gaining traction as a means of responding to rapid technological change.

Experts also highlight the importance of multilevel governance, involving coordination between local, national, and international actors. Such approaches can enhance the effectiveness of regulatory frameworks and promote the alignment of technological innovation with sustainability goals.

6. Discussion

The findings of this study reveal a fundamental tension between the transformative potential of autonomous systems and the challenges they pose for environmental sustainability and governance. This discussion interprets these findings within the broader theoretical and policy context, emphasising the need for integrated and adaptive regulatory frameworks.

6.1 Reconciling Innovation and Sustainability

Autonomous systems represent a double-edged sword in environmental governance. On one hand, they offer unprecedented capabilities for monitoring, predicting, and managing environmental resources. On the other hand, their environmental externalities and governance challenges raise concerns about their long-term sustainability.

This tension reflects a broader challenge in sustainability theory: balancing technological innovation with environmental protection. While innovation is essential for addressing complex environmental problems, it must be guided by principles that ensure its alignment with sustainability objectives (United Nations, 2020). The findings suggest that current approaches to AI governance are insufficient in this regard, as they fail to fully account for environmental impacts.

6.2 Integrating Environmental Law and AI Governance

One of the key implications of this study is the need to integrate environmental law principles into AI governance frameworks. Environmental law provides a well-established set of principles for managing environmental risks, including the precautionary principle, the prevention principle, and the polluter pays principle (De Sadeleer, 2021).

The precautionary principle is particularly relevant for regulating autonomous systems, as it allows policymakers to take preventive action in the face of uncertainty. Given the complexity and opacity of AI systems, it is

often difficult to predict their environmental impacts. The application of the precautionary principle can help mitigate these risks by promoting proactive regulation (Trouwborst, 2009).

Similarly, the polluter pays principle can be adapted to address the environmental externalities of autonomous systems. By assigning responsibility for environmental impacts to developers and operators, this principle can incentivise the adoption of more sustainable practices.

6.3 Addressing Accountability and Transparency

The lack of accountability and transparency in autonomous systems is a major barrier to effective regulation. The “black box” nature of AI systems undermines the ability to assess their environmental impacts and assign responsibility for harm (Jobin et al., 2019).

To address this challenge, regulatory frameworks must incorporate mechanisms for enhancing transparency and accountability. This may include requirements for algorithmic transparency, environmental reporting, and independent audits. In addition, the development of explainable AI technologies can help improve the interpretability of autonomous systems, enabling more effective oversight.

Accountability mechanisms must also be adapted to address the distributed nature of AI systems. This may involve the development of shared responsibility models that allocate liability among multiple actors. Such approaches can help ensure that all stakeholders are held accountable for their contributions to environmental harm.

6.4 The Role of Multilevel Governance

The findings underscore the importance of multilevel governance in regulating autonomous systems. Environmental challenges are inherently global in nature, requiring coordinated action across different levels of governance. However, the current regulatory landscape is characterised by fragmentation and inconsistency, limiting the effectiveness of governance efforts (Batool et al., 2025).

Multilevel governance approaches can help address these challenges by promoting coordination between local, national, and international actors. For example, international standards for AI governance can provide a common framework for regulating autonomous systems, while national regulations can be tailored to local contexts.

In addition, stakeholder participation is essential for ensuring the legitimacy and effectiveness of regulatory frameworks. By involving diverse stakeholders in decision-making processes, policymakers can ensure that regulatory approaches are responsive to societal needs and values (Lemos & Agrawal, 2006).

6.5 Advancing Lifecycle Sustainability

The absence of lifecycle assessments represents a significant gap in current regulatory frameworks. To ensure the sustainability of autonomous systems, it is essential to consider their environmental impacts across all stages of their lifecycle, from production and operation to disposal.

Integrating lifecycle assessments into AI governance frameworks can provide a more comprehensive understanding of the environmental footprint of autonomous systems. This, in turn, can inform the development of sustainability standards and benchmarks. For example, regulators could require organisations to conduct environmental impact assessments as a condition for deploying AI systems.

6.6 Policy Implications and Future Directions

The findings of this study have several important policy implications. First, there is a need for binding regulatory frameworks that incorporate environmental considerations into AI governance. Second, policymakers should promote the adoption of lifecycle assessments and sustainability reporting. Third, international cooperation is essential for addressing the global nature of environmental challenges.

Future research should focus on empirical studies and case analyses to further explore the regulatory implications of autonomous systems. In addition, interdisciplinary approaches that integrate insights from law, technology, and environmental science are needed to address the complex challenges identified in this study.

7. Conclusion

The increasing deployment of autonomous systems in environmental governance represents a transformative shift in how natural resources are monitored, managed, and protected. While these technologies offer significant potential to enhance efficiency,

predictive capacity, and decision-making, they also introduce complex challenges that existing regulatory frameworks are not fully equipped to address. This study has demonstrated that the sustainability of autonomous systems cannot be assumed; rather, it must be actively ensured through robust and integrated regulatory approaches.

One of the central findings is the existence of a significant regulatory gap between environmental law and AI governance. While environmental law provides well-established principles for managing ecological risks, such as the precautionary and polluter pays principles, these are not systematically integrated into current AI governance frameworks. Conversely, AI governance initiatives often emphasise ethical considerations but overlook environmental sustainability. Bridging this divide is essential for ensuring that autonomous systems contribute positively to sustainable resource use.

The study also highlights the importance of addressing the environmental externalities associated with autonomous systems, including energy consumption, carbon emissions, and resource-intensive infrastructure. The absence of lifecycle sustainability assessments represents a critical weakness in current regulatory approaches. Incorporating such assessments into governance frameworks would enable a more comprehensive evaluation of environmental impacts and support the development of sustainability standards.

Furthermore, the findings underscore the need for enhanced accountability and transparency in the deployment of

autonomous systems. The opaque nature of algorithmic decision-making complicates the attribution of responsibility for environmental harm, necessitating the development of new legal and regulatory mechanisms. These may include shared liability models, mandatory disclosure requirements, and independent auditing processes.

Effective regulation also requires a multilevel governance approach that facilitates coordination across local, national, and international levels. Given the transboundary nature of environmental challenges, international cooperation is particularly important for establishing harmonised standards and ensuring consistent enforcement.

In conclusion, the sustainable regulation of autonomous systems demands an integrated and adaptive framework that aligns technological innovation with environmental protection. By combining environmental law principles with AI governance mechanisms, policymakers can create a regulatory environment that supports both innovation and sustainability. Future research should focus on empirical validation and the development of practical policy instruments to operationalise these frameworks.

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