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The role of methodological approaches in the forensic support for the investigation of environmental crimes

Yuliia Chornous[1,*]
National Academy of Internal Affairs
Myroslav Romaniuk[2]
Interregional Academy of Personnel Management
Yevheniia Lypnytska[3]
Igor Sikorsky Kyiv Polytechnic Institute
Tetiana Demianchuk[4]
National Academy of Internal Affairs
Andrii Husak[5]
Lesya Ukrainka Volyn National University

[1] Doctor of Law, Professor, Department of Criminalistics and Forensic Medicine, National Academy of Internal Affairs, Kyiv, Ukraine. ORCID: https://orcid.org/0000-0001-9710-4858; E-mail: uliachornous@gmail.com (corresponding author).
[2] Associate Professor, Department of Law Enforcement and Anti-corruption Activities, Interregional Academy of Personnel Management, Kyiv, Ukraine. ORCID ID: https://orcid.org/0009-0001-3157-0036; E-mail: Rom_Mir@gmail.com.
[3] PhD, Associate Professor, Faculty of Sociology and Law, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine. ORCID ID: https://orcid.org/0000-0003-4608-1734;E-mail: lypny.yevheniia@gmail.com.
[4] PhD, Doctoral Student, Department of Theory of State and Law, National Academy of Internal Affairs, Kyiv, Ukraine. ORCID: https://orcid.org/0000-0002-8908-4356; E-mail: demyantanya@gmail.com.
[5] Doctor of Law, Associate Professor, Department of Criminal Law and Procedure, Lesya Ukrainka Volyn National University, Lutsk, Ukraine. ORCID: https://orcid.org/0000-0002-2142-5193; E-mail: andmax@ukr.net.

Abstract: This paper examines how methodological approaches affect forensic support for environmental crimes within continental legal systems. It analyses how legal rules and procedures determine whether environmental monitoring data and expert findings are considered reliable and admissible evidence. The study applies a comparative doctrinal method, including systematic and comparative analysis and legal diagnostics. It reviews criminal, procedural, and environmental laws of Ukraine, Poland, Germany, and France, together with relevant EU standards adopted after 2020. The results show that effective forensic support depends on a clear and integrated evidentiary framework. Three regulatory models are identified: code-centric, regulatory-integrated, and combined. These models reflect different links between environmental norms, procedural rules, and evidentiary requirements. The study finds recurring problems: unclear definitions of environmental damage, inconsistent procedural status of environmental control materials, and fragmented rules on expert involvement. These weaknesses reduce evidence reliability and admissibility. The paper contributes a structured framework for evaluating forensic support as a legal system, not only a technical process. It also shows that recent EU law strengthens proof and traceability requirements while preserving national procedural autonomy in contemporary practice.

Keywords: Environmental Crimes, Forensic Support, Methodological Approaches, Evidence, Special Knowledge, Admissibility of Evidence

1. Introduction

The growing scale of environmental offences, the increasing complexity of industrial and technogenic processes, and the expansion of transnational environmental risks in 2020–2025 have significantly intensified the demand for effective criminal law responses to environmental violations[6]. Environmental crimes are characterized by high latency, complex causal structures, and a strong dependence on specialized knowledge, which together increase the evidentiary burden in criminal proceedings[7]. Under such conditions, the effectiveness of enforcement depends not only on the existence of criminal prohibitions, but also on the capacity of legal systems to ensure procedurally admissible, verifiable, and reproducible methods for collecting, processing, and evaluating factual data[8].

Recent research demonstrates rapid development in applied areas of forensic science relevant to environmental investigations. For example, Estoppey et al.[9]

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[6] HUBANOVA, T.; SHCHOKIN, R.; HUBANOV, O.; ANTONOV, V.; SLOBODIANIUK, P.; PODOLYAKA, S. "Information technologies in improving crime prevention mechanisms in the border regions of southern Ukraine", Journal of Information Technology Management, 13, 2021, pp. 75–90. https://doi.org/10.22059/JITM.2021.80738

[7] LOIMA, T.; YOON, J.-Y.; KAARJ, K. "Microfluidic sensors integrated with smartphones for applications in forensics, agriculture, and environmental monitoring", *Micromachines*, 16(7), 2025, pp. 835. https://doi.org/10.3390/mi16070835

[8] LYTVYN, N.; ANDRUSCHENKO, H.; ZOZULYA, Y. V.; NIKANOROVA, O. V.; RUSAL, L. M. "Enforcement of court decisions as a social guarantee of protection of citizens' rights and freedoms", *Prawo i Więź*, (39), 2022, pp. 80–102. https://doi.org/10.36128/priw.vi39.351

[9] ESTOPPEY, N.; PFEIFFER, F.; GLANZMANN, V.; REYMOND, N.; TASCON, I.; HUISMAN, S.; LACOUR, W.; RIBAUX, O.; WEYERMANN, C. "The role of forensic science in the generation of

highlight the role of forensic methods in generating analytical intelligence for environmental monitoring, particularly in water contamination cases. Abbasi[10] and Mores et al[11]. emphasize the evidentiary potential of specialized forensic domains, including entomology and animal forensics, while Noor et al.[12] (2024) underline the importance of innovations in evidence collection and preservation. In parallel, Asasfeh et al.[13] analyse the evolution of digital forensics in response to increasingly complex forms of crime, including those with environmental dimensions.

However, the existing literature predominantly focuses on technological and analytical advancements, often without sufficient consideration of the legal and procedural conditions under which such knowledge acquires evidentiary value[14]. In particular, limited attention has been paid to how methodological approaches—such as systemic, comparative, and procedure-oriented approaches—structure the integration of forensic results into legally admissible evidence[15]. This creates a gap between the development of forensic capabilities and their effective use within criminal proceedings, especially in the context of environmental crimes, where proof depends on the interaction between environmental regulation, criminal law, and procedural rules[16].

This gap is further accentuated by the evolution of European Union environmental criminal law after 2020, which has strengthened requirements concerning the effectiveness of investigations, proof of environmental harm or risk,

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intelligence to address environmental water contamination problems", WIREs Forensic Science, 5(6), 2023, pp. e1499. https://doi.org/10.1002/wfs2.1499

[10] ABBASI, E. "A review of the advances in insect evidence analysis for estimating postmortem interval and detecting drug toxicity", Journal of Forensic and Legal Medicine, 118, 2025a, pp. 103059. Available at: https://pubmed.ncbi.nlm.nih.gov/41481964/ (accessed on 18 January 2026).

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[12] NOOR, A.; RAZA, A.; REHMAN, F. U. "Recent advances in forensic science for evidence collection and preservation: Innovations in sample handling techniques to enhance analytical accuracy and case-specific investigations", *Forensic Insights and Health Sciences Bulletin*, 2(2), 2024, pp. 60–66. Available at: https://ammanif.com/journal/fi/index.php/home/article/view/63/71 (accessed on 18 January 2026).

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[16] ALAZZAM, F. A. F.; SHAKHATREH, H. J. M.; GHARAIBEH, Z. I. Y.; DIDIUK, I.; SYLKIN, O. "Developing an information model for e-commerce platforms: A study on modern socioeconomic systems in the context of global digitalization and legal compliance", Ingénierie des Systèmes d'Information, 28(4), 2023, pp. 969–974. Available at: https://www.researchgate.net/publication/373881336_Developing_an_Information_Model_for_E-Commerce_Platforms_A_Study_on_Modern_Socio-Economic_Systems_in_the_Context_of_Global_Digitalization_and_Legal_Compliance (accessed on 18 January 2026).

and the traceability of evidentiary data[17]. These developments necessitate a reassessment of forensic support not only within national legal systems, but also in light of supranational standards that influence evidentiary expectations without fully harmonizing procedural mechanisms[18,19].

Against this background, the present study seeks to address the following main research question: RQ1: How do methodological approaches determine the structure and effectiveness of forensic support in the investigation of environmental crimes within continental legal systems?

To operationalize this inquiry, the study is guided by the following sub-questions: RQ2: What regulatory models of forensic support can be identified in the legal systems of Ukraine, Poland, Germany, and France, and what criteria distinguish them? RQ3: How do supranational European Union standards influence national evidentiary frameworks in environmental crime investigations, particularly regarding proof of harm/risk and data traceability?

The aim of the study is to determine the role of methodological approaches in shaping forensic support for the investigation of environmental crimes and to assess the procedural suitability of the resulting models of evidence. To achieve this aim, the study undertakes a comparative analysis of national criminal, criminal procedural, and environmental legislation in Ukraine, Poland, Germany, and France, and evaluates these frameworks against relevant EU legal standards.

The contribution of the article lies in developing a structured analytical framework that conceptualizes forensic support as a legally conditioned evidentiary system rather than a set of isolated forensic techniques. Unlike existing studies that emphasize technological aspects, this research demonstrates that the effectiveness of forensic support depends primarily on the coherence between substantive legal norms, procedural rules, and the regulation of specialized knowledge. By identifying and classifying regulatory models of forensic support, the study provides a basis for understanding systemic differences between jurisdictions and offers practical implications for improving the admissibility and reliability of evidence in environmental crime proceedings.

2. Conceptual framework and definitions

Given the interdisciplinary nature of environmental crime investigations, which combine elements of criminal law, environmental regulation, and forensic science, conceptual clarity is essential for ensuring analytical consistency. This study relies on a set of core categories that structure the analysis and are used throughout the manuscript in a consistent and operationalized manner.

Forensic support is understood as a legally and procedurally conditioned system that determines the permissible methods of detecting, recording, analysing, verifying, and using factual data in criminal proceedings. In the context of environmental crimes, forensic support is not limited to technical tools or expert methods, but includes the normative framework that governs how environmental control data and specialized knowledge are transformed into admissible evidence.

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[17] GARCÍA-JARAMILLO, M.; MARTÍN MOLINA, C.; LEÓN-VARGAS, F.; TORRES, L.; BAENA, A. "A bibliometric analysis of detection methods for clandestine graves in the context of human rights violations", Science & Justice, 66(1), 2026, pp. 101373. Available at: https://www.researchgate.net/publication/398418775_A_bibliometric_analysis_of_detection_methods_for_clandestine_graves_in_the_context_of_human_rights_violations (accessed on 18 January 2026).

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[19] SURAKANTI, S.; GOUNDAR, S.; DWIGHT, J. "Countering anti-forensic tactics in cybercrime investigations: A systematic literature review". 2025. Ibid.

Methodological approaches refer to structured analytical perspectives that determine how forensic support is examined and interpreted. In this study, three complementary approaches are applied. The systemic approach treats forensic support as an integrated evidentiary system formed through the interaction of substantive environmental law, criminal law, and procedural rules. The comparative legal approach enables the identification of similarities and differences between national legal systems and supports the classification of regulatory models. The procedure-oriented approach focuses on the conditions under which factual data acquire evidentiary status, emphasizing admissibility, verifiability, and procedural form.

The concept of the evidentiary circuit is used to describe the continuous and logically ordered process through which factual data move from their initial detection to their evaluation by a court. This circuit includes several interrelated stages: the identification and recording of environmental violations, the preservation and verification of data, the involvement of specialized knowledge, and the procedural consolidation and judicial assessment of evidence. The stability of the evidentiary circuit depends on the absence of gaps or inconsistencies between these stages.

Procedural suitability of control materials refers to the capacity of data obtained through environmental monitoring, inspections, measurements, or administrative control activities to be used as evidence in criminal proceedings. Such suitability is determined by compliance with procedural requirements, including lawful collection, traceability of origin, integrity of data, and the possibility of independent verification. Control materials that do not meet these conditions risk being excluded or assigned reduced probative value.

Legal diagnostics is applied as an analytical method aimed at identifying regulatory and procedural factors that affect the effectiveness of forensic support. It involves the systematic evaluation of legal norms and practices in order to detect stable configurations that ensure evidentiary reliability, as well as problematic areas that generate risks of inadmissibility, evidentiary gaps, or disputes regarding the probative value of data.

These conceptual definitions provide the analytical foundation for the study and ensure coherence between the research questions, methodology, and interpretation of results. They also allow for a more precise distinction between technological forensic capabilities and the legal conditions under which such capabilities acquire evidentiary significance.

3. Literature review

In 2020–2025, academic discourse on forensic support for complex categories of crime has developed along two partially disconnected trajectories: the expansion of specialized forensic technologies and the analysis of legal frameworks governing evidence in criminal proceedings. While both strands are highly relevant to environmental crime investigations, their integration remains limited, particularly in relation to the procedural conditions under which forensic results acquire evidentiary value.

A significant body of research has focused on the rapid development of analytical capabilities in forensic science. For example, Raj et al.[20] demonstrate the growing potential of LC–MS proteomics for identifying biological traces, highlighting increased precision in forensic identification. Similarly, Adav and

[20] RAJ, T. A.; ARAVIND, G. B.; ARUN, M.; ANEESH, E. M. "Mass spectrometry- based proteomics in forensic investigations: A focused review of LC-MS applications", *Egyptian Journal of Forensic Sciences,* 15, 2025, pp. 75. https://doi.org/10.1186/s41935-025-00484-8

Ng[21], analyse hair as a multifunctional biomaterial, emphasizing its expanding evidentiary applications. These studies illustrate the increasing sensitivity and diversity of forensic tools, but they largely concentrate on technical performance rather than the legal requirements governing admissibility, reliability, and interpretation of results in criminal proceedings.

Parallel developments can be observed in research on event reconstruction and digital forensics, where methodological rigor is increasingly recognized as a condition for evidentiary value. Harrison K. [22] links forensic reconstruction to spatial and temporal coordinates, demonstrating that the structured integration of methods enhances the formation of a coherent evidentiary chain. In digital forensics, Horsman[23] shifts attention from data extraction to interpretative frameworks, arguing that evidentiary reliability depends on the logic of inference. Likewise, Hamid and Rahman[24] show that the procedural applicability of digital data is closely tied to standardized methods of data capture and integrity control. These studies suggest that methodological discipline, rather than purely technological advancement, is central to evidentiary reliability.

A further strand of literature addresses the role of specialized knowledge in contexts directly relevant to environmental crime investigations.

Yatsenko[25] highlights the procedural challenges of forming expert conclusions in veterinary forensic examinations, emphasizing the importance of properly defined expert tasks and procedural conditions. At the same time, research on artificial intelligence in forensic contexts, such as the bibliometric analysis by Díaz et al.[26] demonstrates the rapid growth of analytical capabilities while indicating that procedural and legal constraints on the use of such technologies remain underexplored. This reflects a broader imbalance between technological innovation and its legal integration.

The same pattern is evident in studies on advanced forensic methodologies. Orsini et al.[27] show that artificial intelligence can support diagnostic processes in forensic pathology, but stress that interpretability and quality control remain decisive for evidentiary acceptance. Radu et al.[28] emphasize that digitalization in forensic odontology enhances analytical efficiency but increases dependence on

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[27] ORSINI, F.; CIOFFI, A.; CIPOLLONI, L.; BIBBÒ, R.; MONTANA, A.; DE SIMONE, S.; CECANNECCHIA, C. "The application of artificial intelligence in forensic pathology: A systematic literature review", *Frontiers in Medicine*, 12, 2025, pp. 1583743. https://doi.org/10.3389/fmed.2025.1583743

[28] RADU, C. C.; HOGEA, T.; CARAȘCA, C.; RADU, C.-M. "Forensic odontology in the digital era: A narrative review of current methods and emerging trends", *Diagnostics*, 15(20), 2025, pp. 2550. https://doi.org/10.3390/diagnostics15202550

standardized procedures for data validation and preservation. Similarly, Abbasi[29] demonstrates that advances in forensic entomology require careful consideration of environmental variables and control procedures, while Nkhoma et al.[30] confirm that long-term validation and reproducibility are essential for evidentiary stability. Collectively, these studies indicate that technological progress does not eliminate the need for procedural standardization; rather, it reinforces it.

In parallel, an emerging line of research connects forensic science more directly with environmental considerations. Ünal et al.[31] examine "greener approaches" in forensic science, highlighting the environmental impact of forensic practices themselves, including the use of less toxic materials and more sustainable laboratory processes. At the same time, they emphasize that environmental sustainability does not automatically translate into procedural suitability, as criminal proceedings prioritize reproducibility, accuracy, and validation. This reinforces the distinction between technical feasibility and evidentiary admissibility.

Despite these important developments, the literature remains fragmented with regard to the legal dimension of forensic support in environmental crime investigations. Existing studies rarely address how environmental regulation, criminal law, and procedural rules interact to determine the admissibility and evidentiary value of data obtained through environmental monitoring and control. In particular, limited attention has been given to the procedural transformation of environmental control materials into evidence and to the conditions under which specialized knowledge becomes legally relevant within criminal proceedings.

This gap is especially significant in the context of environmental crimes, where proof often depends on complex interactions between regulatory standards, scientific data, and procedural requirements. While forensic science literature provides valuable insights into data generation and analysis, it does not sufficiently explain how such data are integrated into legal frameworks of proof. Conversely, legal scholarship on environmental crime has only partially engaged with the methodological conditions of forensic evidence, particularly in comparative and EU contexts. In parallel, legal scholarship on environmental criminal law has increasingly focused on the role of evidentiary standards and procedural guarantees in ensuring effective enforcement. Recent studies emphasize that the effectiveness of environmental crime prosecution depends on the alignment between substantive environmental norms, criminal law provisions, and procedural rules governing the admissibility and evaluation of evidence. In the European Union context, Directive (EU) 2024/1203 has reinforced requirements related to proof of environmental harm, risk-based liability, and the traceability of evidentiary data, while preserving national procedural autonomy. This has led to growing scholarly attention to the interaction between regulatory frameworks and evidentiary processes, particularly in relation to the use of scientific and monitoring data in criminal

[29] ABBASI, E. "Forensic entomology in criminal investigations: Advances in insect-mediated postmortem interval estimation, species identification, and environmental influences", *The American Journal of Forensic Medicine and Pathology*, 46(4), 2025b, pp. 298–306. https://doi.org/10.1097/PAF.0000000000001067

[30] NKHOMA, T. B.; RAKOPOULOU, G. D.; FORTNEY, S. H.; WESCOTT, D. J.; SPRADLEY, K. M.; DADOUR, I. R. "A synopsis of two decades of arthropod related research at the Forensic Anthropology Research Facility (FARF), Texas State University (TXST), San Marcos, Texas, USA", *Insects*, 16(9), 2025, pp. 897. https://doi.org/10.3390/insects16090897

[31] ÜNAL, B. K.; UYSAL, S.; UZUN, L. "Greener approaches/materials for forensic sciences", *Forensic Science and Technology*, 2024, pp. 1–21. https://doi.org/10.1080/28378083.2024.2434238

proceedings. However, the role of methodological approaches in structuring this interaction remains insufficiently examined, especially in comparative perspective.

Accordingly, this study contributes to the existing literature by bridging these two strands of research. It does so by analysing forensic support as a legally structured evidentiary system shaped by methodological approaches and by examining how different legal systems regulate the transformation of environmental data and specialized knowledge into admissible and verifiable evidence. In doing so, the study responds to the need for a more integrated understanding of forensic support that connects technological capabilities with legal and procedural conditions of proof. Accordingly, this study addresses this gap by integrating doctrinal legal analysis with a structured methodological framework that allows for the systematic comparison of evidentiary models across jurisdictions.

4. Methodology

This study employs a structured comparative doctrinal design aimed at identifying how legal and procedural frameworks shape forensic support for the investigation of environmental crimes. The methodological approach integrates systemic analysis, comparative legal analysis, and legal diagnostics in order to examine forensic support as a legally conditioned evidentiary system rather than a set of isolated technical tools.

4.1. Analytical framework

The examination of forensic support was conducted using a comprehensive theoretical model, which describes support through three interconnected types of dimensions: (1) Legal substantive dimension – construction of the offenses of an environmental character, such as definition of environmental obligations, prohibitions, and criteria defining the level of environmental harm or risk; (2) Procedural dimension – the rules governing the collection, documentation, storage, verification, and acceptance of factual information in criminal procedures; (3) Forensic (epistemic) dimension – the role and regulatory aspects of special knowledge, such as participation of experts and transformation of technical information into evidence acceptable in court.

Dimensions were implemented by means of a set of criteria of comparison, used consistently in all examined countries, which were: Degree of legal certainty of environmental obligations and damage criteria; Status of the procedural and admissibility of environmental control materials; Regulation of participation of experts and special knowledge; Continuity and integrity of the evidentiary process from the time of collection of the data until its assessment by courts.

Using this model, it was possible to identify similarities in how legal systems organize the "circuit of evidence" and provide a basis for classification of national models of forensic support.

4.2. Selection of jurisdictions

The study focuses on Ukraine, Poland, Germany, and France. The selection is based on the following criteria: belonging to a continental legal tradition, which ensures comparability of procedural mechanisms; the presence of codified criminal and criminal procedural legislation; different models of interaction between criminal law and special environmental regulation; practical relevance for assessing the impact of European Union law.

Such selection allows for controlled comparison within a shared legal tradition while capturing meaningful variation in regulatory design.

4.3. Data sources (legal materials)

The empirical basis of the study consists of a corpus of legal sources, rather than a statistical sample. The analysis includes: national criminal codes and criminal procedure codes; core environmental legislation relevant to environmental offences; supranational EU legal acts, in particular Directive (EU) 2024/1203[32] and Regulation (EU) 2024/1157[33].

The use of official legal databases (zakon.rada.gov.ua, isap.sejm.gov.pl, gesetze-im-internet.de, legifrance.gouv.fr, eur-lex.europa.eu) ensures the validity and reproducibility of the analysis. The selected legal materials were chosen based on their direct relevance to the regulation of environmental crimes and evidentiary processes.

4.4. Comparative procedure and derivation of models

To ensure methodological transparency and reproducibility, the comparative analysis was operationalized through a structured multi-stage procedure based on an explicit analytical matrix and standardized coding rules. This procedure enabled the systematic transformation of legal norms into comparable analytical units and ensured that the classification of regulatory models was derived from observable and replicable criteria rather than interpretative inference.

Stage 1. Normative mapping (data extraction and structuring)

At the first stage, legal norms from each jurisdiction were systematically extracted and organized using a unified analytical matrix. The matrix was constructed in accordance with the three analytical dimensions defined in Section 4.1 (substantive, procedural, and forensic/epistemic) and included the following variables:

S1 – Definition of environmental obligations and prohibitions (clarity and legal certainty);

S2 – Criteria of environmental harm or risk (thresholds, formalization, evidentiary relevance);

P1 – Procedural status of environmental control materials (independent evidentiary value vs. need for procedural transformation);

P2 – Requirements for admissibility and verification (traceability, documentation continuity, integrity of data);

F1 – Regulation of expert involvement and specialized knowledge (mandatory, optional, or auxiliary role);

F2 – Continuity of the evidentiary circuit (presence or absence of procedural gaps between data collection and judicial evaluation).

Each variable was extracted from statutory provisions and interpreted using the dogmatic method to ensure consistency of legal meaning across jurisdictions.

Stage 2. Coding and standardization of legal features

To ensure analytical rigor and avoid interpretative circularity, the coding procedure was based on externally defined and operationalized criteria, independent from the subsequent model classification. Each variable within the

[32] EUROPEAN UNION. Directive (EU) 2024/1203 of the European Parliament and of the Council of 11 April 2024 on the protection of the environment through criminal law and replacing Directives 2008/99/EC and 2009/123/EC. Official Journal of the European Union, L 2024/1203, 30 April 2024. Available at: https://eur-lex.europa.eu/eli/dir/2024/1203/oj (accessed on 02 June 2026).

[33] EUROPEAN UNION. Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 (Text with EEA relevance). Official Journal of the European Union, L 2024/1157, 30 April 2024. Available at: https://eur-lex.europa.eu/eli/reg/2024/1157/oj (accessed on 02 June 2026).

analytical matrix (S1–S2; P1–P2; F1–F2) was assigned a qualitative level according to three cumulative indicators: (1) Normative explicitness – whether the legal rule is directly articulated in statutory provisions; (2) Procedural enforceability – whether the rule produces binding procedural consequences within criminal proceedings; (3) Evidentiary autonomy – whether the element can independently influence the admissibility or probative value of evidence without additional transformation.

Based on these indicators, the three-level scale was operationalized as follows: (1) Level 1 (Low/Indirect regulation) – the element is not explicitly defined in statutory law and does not produce independent procedural or evidentiary effects; its relevance is inferred or derived indirectly from general legal principles. (2) Level 2 (Moderate/Conditional regulation) – the element is explicitly recognized in legal norms but its evidentiary function depends on additional procedural steps (e.g., expert validation, judicial interpretation, or transformation into another evidentiary form). (3) Level 3 (High/Direct regulation) – the element is explicitly codified and produces direct procedural and evidentiary effects, including autonomous admissibility or legally predefined evidentiary weight, subject only to standard verification requirements.

For example, the procedural status of environmental control materials (P1) was coded as Level 3 only when statutory provisions explicitly recognized such materials as admissible evidence within criminal proceedings, without requiring transformation into expert conclusions. Where admissibility depended on additional procedural mediation, the variable was coded as Level 2.

This operationalization ensures that coding is rule-based, transparent, and reproducible, thereby preventing overlap between the variables used for classification and the models derived from them.

Stage 2a. Illustrative example of coding and model derivation

To demonstrate the practical application of the analytical matrix and coding procedure, this section provides an illustrative example based on the legal framework of Germany.

At the stage of normative mapping, the following observations were made: (1) Environmental obligations and prohibitions (S1) are defined through sectoral environmental legislation, but their formulation does not directly determine evidentiary criteria in criminal proceedings; (2) Criteria of environmental harm or risk (S2) are present, but their evidentiary significance depends on procedural interpretation; (3) The procedural status of environmental control materials (P1) is clearly regulated within criminal procedure law, allowing such materials to be used as evidence subject to verification; (4) Requirements for admissibility and verification (P2) are strictly defined, including traceability, documentation continuity, and procedural safeguards; (5) The role of expert involvement (F1) is formalized and integrated into the evidentiary process; (6) The evidentiary circuit (F2) is continuous, without structural gaps between data collection and judicial evaluation.

Based on these observations, the variables were coded as follows: S1 = Level 2; S2 = Level 2; P1 = Level 3; P2 = Level 3; F1 = Level 2; F2 = Level 3.

The resulting configuration demonstrates a clear dominance of procedural variables (P1–P2), supported by a stable evidentiary structure (F2), while substantive environmental norms (S1–S2) play a secondary role in shaping evidentiary admissibility.

According to the decision rules defined in Stage 4, this configuration corresponds to a code-centric model, as procedural regulation determines the structure and validation of evidence.

This example illustrates how the analytical matrix, coding procedure, and classification rules operate in a consistent and reproducible manner.

A contrasting example can be observed in the case of Poland. In this jurisdiction, both substantive environmental variables (S1–S2) and procedural variables (P1–P2) are coded at Level 3, reflecting a high degree of integration between environmental regulation and evidentiary procedures. Environmental norms directly shape the subject of proof, while procedural rules ensure admissibility and verification. This configuration corresponds to a regulatory-integrated model, demonstrating how the interaction between dimensions leads to a different evidentiary structure.

Stage 3. Comparative analysis and pattern identification

The coded matrices for each jurisdiction were then compared across all variables. This comparison was conducted horizontally (across jurisdictions) and vertically (across analytical dimensions) to identify stable configurations of legal regulation.

At this stage, particular attention was given to the interaction between dimensions, specifically: whether environmental norms (S1–S2) directly shape the subject of proof; whether procedural rules (P1–P2) dominate evidentiary admissibility; whether forensic elements (F1–F2) function as independent or auxiliary components.

Recurring combinations of coded values were identified as regulatory patterns, reflecting how different legal systems structure the evidentiary circuit in environmental crime investigations.

Stage 4. Model construction (non-circular classification logic)

To avoid tautological reasoning, the classification of regulatory models was conducted using a two-step separation between measurement and interpretation.

First, all variables were coded independently using the operational criteria defined in Stage 2, without reference to any predefined model structure.

Second, model classification was derived from configurational dominance patterns, identified through the relative distribution of coded values across dimensions. The models were not defined by the variables themselves, but by the structural relationships between them, specifically:

Code-centric model – identified where procedural variables (P1–P2) consistently demonstrate higher regulatory intensity than substantive variables (S1–S2), indicating procedural primacy in evidentiary formation;

Regulatory-integrated model – identified where substantive (S1–S2) and procedural variables (P1–P2) simultaneously reach high levels of regulatory intensity and exhibit functional interdependence in defining the subject and structure of proof;

Combined model – identified where no single dimension is dominant and evidentiary outcomes depend on conditional interaction between variables across dimensions.

Thus, models are not constructed from individual variables, but emerge from systemic configurations, ensuring that classification remains analytically independent from the coding process.

Stage 5. Validation of classification

The resulting classification was cross-checked against the full set of legal materials for each jurisdiction to confirm internal consistency. This validation ensured that the assigned model reflects not isolated provisions, but the overall structure of forensic support within each legal system.

This operationalized procedure ensures that the derivation of regulatory models is transparent, reproducible, and analytically grounded, thereby addressing potential subjectivity in comparative legal interpretation and strengthening the methodolo gical rigor of the study.

For example, in the German case, consistency across four of the six variables (P1, P2, F2, and partially F1) confirms the dominance of procedural regulation, thereby validating its classification as a code-centric model. Similar consistency is observed in Poland, where all core variables reach Level 3, supporting its classification as a regulatory-integrated model. This confirms that model assignment is based on stable and reproducible configurations rather than isolated legal provisions.

4.5. Methodological tools

The study applies the following methods: (1) Systemic method, used to analyse forensic support as an integrated evidentiary system; (2) Comparative legal method, used to identify similarities and differences between jurisdictions; (3) Dogmatic method, used for the interpretation of key legal categories (environmental crime, damage, causality, admissibility of evidence, expert knowledge); (4) Legal diagnostics, used to identify regulatory and procedural factors affecting evidentiary reliability and effectiveness.

The results of the comparison were systematized in a structured analytical matrix to ensure consistency and transparency of classification.

4.6. Limitations of the study

The study has several methodological limitations that should be taken into account when interpreting the results. First, this study is mainly doctrinal and will focus primarily on normative legal documents. Therefore, the study did not include empirical data about how criminal cases are enforced or judicial decisions based on case law. Secondly, although the jurisdiction selected may be justifiable, the study does not attempt to represent the variety of legal systems that exist throughout the European Union. Thirdly, the study does not intend to assess whether specific forensic methods are technically effective, but rather what legal conditions apply to allow such methods to become evidence.

Despite these limitations, the methodology allowed for a consistent and theoretically grounded comparison of legal frameworks and for the identification of systemic patterns of forensic support in environmental crime investigations.

5. Results

The results derive directly from the operationalized analytical matrix described in Section 4.4 and reflect the comparative configuration of six standardized variables (S1–S2; P1–P2; F1–F2) across the examined jurisdictions. Rather than restating the analytical framework, this section presents empirical outcomes of the coding procedure, focusing on how variations in regulatory intensity and interaction between variables shape distinct evidentiary structures.

5.1. Structure of forensic support and evidentiary logic

The analysis demonstrates that forensic support in environmental crime investigations is structured through the interaction of three legally defined dimensions: substantive norms, procedural rules, and forensic (epistemic) elements. These dimensions do not operate independently; instead, they form an integrated evidentiary framework in which the role of each component varies depending on its degree of regulatory formalization and procedural effect.

In all examined jurisdictions, the evidentiary structure was organized as a sequential process in which four elements had to be established: violation of an environmental obligation or prohibition, environmental damage or significant environmental risk, causation, and fault.

However, the analysis demonstrates that the distribution of evidentiary significance differs depending on how damage criteria are defined and how environmental control materials are incorporated into criminal procedure in each country.

5.2. Derivation and classification of regulatory models

The application of the analytical matrix and coding procedure described in Section 4.4 resulted in a structured dataset reflecting the configuration of legal variables across the examined jurisdictions. Each legal system was evaluated against six standardized variables (S1–S2; P1–P2; F1–F2), allowing for the identification of dominant regulatory patterns in the organization of forensic support. The results of this comparative coding are presented in Table 1. The table constitutes the primary empirical output of the study and provides the basis for the subsequent classification of regulatory models.

Table 1. Analytical matrix and classification of regulatory models of forensic support.

Country	S1	S2	P1	P2	F1	F2	Dominant pattern	Model type
Ukraine	3	3	2	3	2	2	Mixed (S–P interaction)	Combined
Poland	3	3	3	3	3	3	Integrated (S + P dominance)	Regulatory-integrated
Germany	2	2	3	3	2	3	Procedural dominance	Code-centric
France	2	2	3	3	2	3	Procedural dominance	Code-centric

Note: S1–S2 = substantive variables (environmental obligations; harm/risk criteria); P1–P2 = procedural variables (status and admissibility of control materials); F1–F2 = forensic variables (expert involvement; continuity of evidentiary circuit). Coding scale: 1 = low/indirect regulation; 2 = conditional/moderate regulation; 3 = high/direct regulation. Source: developed by the authors based on analytical matrix described in Section 4.4.

As shown in Table 1, the comparative configuration of variables demonstrates that the structure of forensic support is determined by the relative dominance and interaction of substantive, procedural, and forensic elements within each legal system.

The coded values reveal three distinct patterns. First, in Germany and France, procedural variables (P1–P2) consistently reach the highest level of regulatory intensity (Level 3), while substantive environmental variables (S1–S2) are less determinative for evidentiary admissibility. This indicates that the formation and validation of evidence are governed primarily by criminal procedural law, with environmental regulation serving a subsidiary role in defining the content of obligations. The forensic dimension (F1–F2) operates within this procedural framework, reinforcing verification and evidentiary integrity. This configuration corresponds to a code-centric model, characterized by procedural dominance in the evidentiary circuit.

Second, Poland demonstrates a configuration in which both substantive (S1–S2) and procedural variables (P1–P2) are consistently coded at Level 3, indicating a high degree of formalization and direct interaction between environmental regulation and evidentiary procedures. Environmental norms actively shape the subject and structure of proof, while procedural rules ensure the admissibility and verification of control materials. The forensic dimension further supports this integration by linking specialized knowledge to regulatory criteria. This pattern corresponds to a regulatory-integrated model, in which evidentiary frameworks emerge through the convergence of substantive and procedural regulation.

Third, Ukraine exhibits a mixed configuration, in which substantive variables (S1–S2) are highly developed, but the procedural status of environmental control materials (P1) remains conditional (Level 2), requiring additional procedural transformation to achieve evidentiary admissibility. Procedural rules (P2) impose strict verification requirements, while the forensic dimension (F1–F2) plays a mediating role in integrating environmentally derived data into the evidentiary process. This combination of conditional interaction between dimensions corresponds to a combined model, reflecting a hybrid structure of forensic support.

These results confirm that the classification of regulatory models is directly grounded in the comparative configuration of coded legal variables. The transition from analytical matrix to model typology is therefore not interpretative, but follows a transparent and reproducible logic based on observable regulatory patterns.

5.3. Influence of EU supranational standards

The analysis of Directive (EU) 2024/1203[34] and Regulation (EU) 2024/1157[35] demonstrates that the supranational level does not impose a uniform model of forensic support, but establishes performance-oriented requirements that influence national systems indirectly. These include: strengthened requirements for proving environmental damage or serious risk; increased emphasis on traceability and reliability of data; higher expectations regarding the effectiveness of investigations. Figure 1 illustrates the relationship between EU standards and national models.

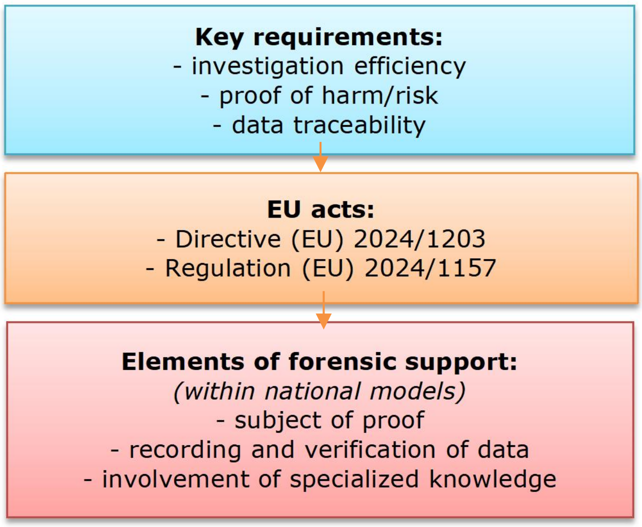

Figure 1. The relationship between supranational EU standards and national models of forensic support for the investigation of environmental crimes. Source: developed by the author based on Directive[36] and Regulation [37]

The figure is derived from the mapping of supranational requirements onto the analytical dimensions of forensic support. It shows that EU law operates as a framework of functional benchmarks, which adjust the structure of the subject of proof and evidentiary expectations, while leaving procedural mechanisms largely within national competence. As a result, national systems retain procedural autonomy, but must ensure that evidentiary practices meet higher standards of reliability, traceability, and demonstrability of harm or risk.

[34] EUROPEAN UNION. Directive (EU) 2024/1203 of the European Parliament and of the Council of 11 April 2024 on the protection of the environment through criminal law and replacing Directives 2008/99/EC and 2009/123/EC. 2024. Ibid.
[35] EUROPEAN UNION. Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 (Text with EEA relevance). 2024. Ibid.
[36] EUROPEAN UNION. Directive (EU) 2024/1203 of the European Parliament and of the Council of 11 April 2024 on the protection of the environment through criminal law and replacing Directives 2008/99/EC and 2009/123/EC. 2024. Ibid.
[37] EUROPEAN UNION. Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 (Text with EEA relevance). 2024. Ibid.

5.4. Legal diagnostics of evidentiary effectiveness

The final stage of the analysis involved legal diagnostics, aimed at identifying regulatory and procedural factors that affect the effectiveness of forensic support. The results of this stage are summarized in Table 2.

Table 2. Legal diagnostics of the effectiveness of forensic support for the investigation of environmental crimes.

Diagnostic criterion	**Stable regulatory and procedural configurations**	**Problem areas of regulation**	**Procedural consequences for proving**
Substantive and legal certainty of environmental obligations and damage	The criteria of damage and environmental obligations are directly integrated into the subject of proof and correspond to the procedural rules	Evaluative or scattered criteria of harm without a fixed procedural algorithm of proof	Uncertainty of the subject of evidence and difficulty in establishing a causal relationship
Procedural suitability of factual data	Environmental control materials have a defined status, traceability, and verification regime	Unclear or mixed procedural status of the results of inspections, measurements, and prescriptions	Increased risks of recognizing evidence as inadmissible or insufficiently convincing
Involvement of special knowledge and expertise	Clearly defined grounds, boundaries and methods of expert research with the possibility of independent verification	Fragmented requirements for examinations and lack of a transparent transition from data to conclusion	Reduced verifiability, reproducibility, and probative value of expert results
Procedural sequence of proof	Logically ordered evidentiary chain from initial recording to judicial assessment	Discontinuities between the stages of recording, analysis, and procedural consolidation of facts	Loss of integrity of the evidentiary circuit and increased number of procedural disputes

Source: created by the authors based on an analysis of the Criminal Code of Ukraine[38], Criminal Procedure Code of Ukraine[39], Kodeks karny[40], Law of Ukraine "On Waste Management"[41], Law of Ukraine "On Integrated Prevention and Control of Industrial Pollution"[42], Kodeks postępowania karnego[43], Prawo ochrony środowiska[44], Strafgesetzbuch[45],

[38] VERKHOVNA RADA OF UKRAINE. Criminal Code of Ukraine, Law No. 2341-III of 5 April 2001. Database "Legislation of Ukraine". Available at: https://zakon.rada.gov.ua/laws/show/2341-14?lang=en (accessed on 02 June 2026).

[39] VERKHOVNA RADA OF UKRAINE. Criminal Procedure Code of Ukraine, Law No. 4651-VI of 13 April 2012. Database "Legislation of Ukraine". Available at: https://zakon.rada.gov.ua/laws/show/4651-17?lang=en (accessed on 02 June 2026).

[40] SEJM RZECZYPOSPOLITEJ POLSKIEJ. Ustawa z dnia 6 czerwca 1997 r. – Kodeks karny, Dz.U. 1997 nr 88 poz. 553. Internetowy System Aktów Prawnych. Available at: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu19970880553 (accessed on 02 June 2026).

[41] VERKHOVNA RADA OF UKRAINE. Law of Ukraine "On Waste Management", No. 2320-IX of 20 June 2022. Database "Legislation of Ukraine". Available at: https://zakon.rada.gov.ua/laws/show/2320-20 (accessed on 02 June 2026).

[42] VERKHOVNA RADA OF UKRAINE. Law of Ukraine "On Integrated Prevention and Control of Industrial Pollution", No. 3855-IX of 16 July 2024. Database "Legislation of Ukraine". Available at: https://zakon.rada.gov.ua/laws/show/3855-20 (accessed on 02 June 2026).

[43] SEJM RZECZYPOSPOLITEJ POLSKIEJ. Ustawa z dnia 6 czerwca 1997 r. – Kodeks postępowania karnego, Dz.U. 1997 nr 89 poz. 555. Internetowy System Aktów Prawnych.

Strafprozessordnung[46], Kreislaufwirtschaftsgesetz[47], Code pénal[48], Code de procédure pénale[49], Code de l'environnement[50], as well as acts of EU law – Directive[51] and Regulation[52].

Legal diagnostics was based on the relationship between legally established rules and procedures for producing evidence. Four factors contributing to evidentiary stability were identified: certainty of environmental requirements and damage-assessment standards; procedural suitability of environmental control materials; clear and transparent regulation of scientific and technical knowledge; and continuity of evidence generation from the collection of primary data to judicial evaluation.

Each diagnostic criterion was correlated with stable regulatory configurations, problem areas, and procedural consequences. Table 2 therefore presents a systematic comparison of how the examined legal systems regulate the conversion of environmental data into evidence.

Three of these types of situations represent the greatest potential vulnerabilities in forensic support: where damage criteria are evaluative, fragmented and/or lack a clear procedural method of proof; where the procedural status of environmental control materials is ambiguous (or mixed), thereby limiting their admissibility; where there is inadequate regulation of the involvement of scientific/technical knowledge, and therefore inadequate transparency in converting data into expert conclusions.

These limitations create risks of evidentiary inadmissibility, reduced probative value, and procedural disputes.

5.5. Generalized findings

The findings show that forensic support for environmental crime investigations depends on the coherence of the regulatory and procedural structure of evidence

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Available at: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu19970890555 (accessed on 02 June 2026).

[44] SEJM RZECZYPOSPOLITEJ POLSKIEJ. Ustawa z dnia 27 kwietnia 2001 r. – Prawo ochrony środowiska, Dz.U. 2001 nr 62 poz. 627. Internetowy System Aktów Prawnych. Available at: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=wdu20010620627 (accessed on 02 June 2026).

[45] BUNDESMINISTERIUM DER JUSTIZ. Strafgesetzbuch (StGB). Gesetze im Internet. Available at: https://www.gesetze-im-internet.de/stgb/ (accessed on 02 June 2026).

[46] BUNDESMINISTERIUM DER JUSTIZ. Strafprozessordnung (StPO). Gesetze im Internet. Available at: https://www.gesetze-im-internet.de/stpo/ (accessed on 02 June 2026).

[47] BUNDESMINISTERIUM DER JUSTIZ. Kreislaufwirtschaftsgesetz (KrWG). Gesetze im Internet. Available at: https://www.gesetze-im-internet.de/krwg/ (accessed on 02 June 2026).

[48] RÉPUBLIQUE FRANÇAISE. Code pénal. Légifrance. Available at: https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000006070719/ (accessed on 02 June 2026).

[49] RÉPUBLIQUE FRANÇAISE. Code de procédure pénale. Légifrance. Available at: https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000006071154/ (accessed on 02 June 2026).

[50] RÉPUBLIQUE FRANÇAISE. Code de l'environnement. Légifrance. Available at: https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000006074220/ (accessed on 02 June 2026).

[51] EUROPEAN UNION. Directive (EU) 2024/1203 of the European Parliament and of the Council of 11 April 2024 on the protection of the environment through criminal law and replacing Directives 2008/99/EC and 2009/123/EC. 2024. Ibid.

[52] EUROPEAN UNION. Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 (Text with EEA relevance). 2024. Ibid.

rather than on the mere availability of forensic tools. A similar structural relationship was identified across the examined jurisdictions: environmental obligations and damage criteria → methods and means of proof → regulatory frameworks for specialized knowledge.

Variation among the national systems stems from the degree of legal formalization and procedural implementation of these relationships. The application of EU standards will increase the burden of proof of damage/risk and data traceability, but it does not preclude national differences in procedural mechanisms.

6. Discussion

The findings demonstrate that forensic support in environmental crime investigations is structured through stable interactions between substantive, procedural, and forensic dimensions, rather than through isolated legal provisions. The comparative analysis confirms that evidentiary systems are shaped by configurational relationships between legal elements, which determine how environmental data are transformed into admissible and probative evidence. This supports the central argument of the study: the effectiveness of forensic support depends on the internal coherence of evidentiary frameworks, not on the availability of advanced forensic techniques.

A key methodological contribution of the study lies in demonstrating that these configurations can be identified through a non-circular analytical procedure. By separating the stages of variable coding and model classification, the research shows that regulatory models emerge from observable legal structures rather than being defined by the same variables used to construct them. This strengthens the explanatory value of the proposed typology and ensures its applicability in comparative legal analysis.

6.1. Methodological approaches and the structure of forensic support (RQ1)

The results confirm that methodological approaches play a constitutive role in shaping forensic support as a legal phenomenon. The systemic approach reveals that evidentiary processes in environmental crime investigations function as integrated circuits, in which the breakdown of any element—substantive definition, procedural regulation, or forensic validation—undermines the integrity of the entire evidentiary structure. This perspective shifts the focus from individual evidentiary acts to the continuity and interdependence of procedural stages.

The procedure-oriented approach further clarifies that evidentiary value is not inherent in environmental data but is constructed through compliance with procedural requirements, including traceability, verifiability, and lawful collection. This explains why similar types of environmental data may have different evidentiary outcomes across jurisdictions: their admissibility depends on procedural integration rather than technical reliability alone.[53]

The comparative approach enables the identification of recurrent structural patterns, demonstrating that differences between legal systems are not random but reflect distinct configurations of regulatory priorities. Importantly, the use of operationalized coding criteria ensures that these patterns are derived from measurable legal characteristics, thereby avoiding circular reasoning and reinforcing the methodological robustness of the findings.[54]

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[53] ROSS, A.; LENNARD, C.; ROUX, C. "Forensic science: Where to from here?", *Forensic Science International*, 366, 2025, pp. 112285. Available at: https://pubmed.ncbi.nlm.nih.gov/39566344/ (accessed on 18 January 2026).

[54] CINAR, B.; BHARADIYA, J. P. "Cloud computing forensics: Challenges and future perspectives: A review", Asian Journal of Research in Computer Science, 16(1), 2023, pp. 1–14. https://doi.org/10.9734/ajrcos/2023/v16i1330

Taken together, these approaches establish that forensic support should be understood not as a technical supplement to criminal investigations, but as a methodologically structured evidentiary system, governed by identifiable legal principles.

6.2. Regulatory models and comparative legal implications (RQ2)

The identification of three regulatory models—code-centric, regulatory-integrated, and combined—demonstrates that variation between legal systems is primarily structural rather than quantitative. The models differ not in the availability of forensic tools, but in how legal norms organize the production, validation, and interpretation of evidence.

The code-centric model prioritizes procedural formalization, ensuring high levels of evidentiary consistency and reproducibility. However, this structure may limit the direct incorporation of environmental regulatory data, as such data must be adapted to procedural requirements before acquiring evidentiary status.

The regulatory-integrated model reflects a higher degree of interaction between environmental law and criminal procedure, allowing environmental norms to directly shape the subject of proof. While this enhances the substantive relevance of evidence, it also increases the complexity of ensuring procedural safeguards and consistency in evidentiary evaluation.

The combined model illustrates a hybrid configuration in which evidentiary outcomes depend on conditional interaction between dimensions. This flexibility may allow adaptation to complex environmental cases, but it also introduces risks of inconsistency, particularly where procedural rules do not fully align with substantive environmental criteria.

These distinctions contribute to comparative environmental criminal law by demonstrating that forensic support is not a neutral technical domain, but a product of legal architecture. The findings show that evidentiary effectiveness depends on how legal systems balance procedural control with substantive integration, thereby shaping both the scope and reliability of environmental crime enforcement.

6.3. Influence of EU law and supranational standards (RQ3)

The analysis shows that European Union law influences national forensic support systems through functional evidentiary requirements, rather than through detailed procedural harmonization. Directive (EU) 2024/1203 and Regulation (EU) 2024/1157 establish higher standards for proving environmental harm or serious risk, while emphasizing the importance of data traceability and reliability.

However, these instruments do not prescribe specific procedural mechanisms for achieving these standards. As a result, national legal systems retain procedural autonomy but must adapt their evidentiary frameworks to meet increased performance expectations. This creates a regulatory dynamic in which compliance depends on the ability of domestic systems to ensure coherence between environmental norms, procedural rules, and forensic practices.

This finding aligns with broader trends in EU environmental law, where harmonization is achieved through performance-based obligations rather than uniform procedural rules. Consequently, the effectiveness of environmental crime investigations depends not only on formal compliance with EU standards, but on the institutional capacity of national systems to translate these standards into operational evidentiary practices.

6.4. Doctrinal and practical implications

From a doctrinal perspective, the study reconceptualizes forensic support as an integral component of the law of evidence, rather than as a purely technical or auxiliary domain. This shift has important implications for legal theory, as it situates forensic processes within the broader framework of evidentiary regulation and procedural justice. The concept of the evidentiary circuit provides a useful analytical tool for identifying points of vulnerability within this system, particularly where discontinuities undermine evidentiary integrity.

From a practical perspective, the findings indicate that improving the effectiveness of environmental crime investigations requires targeted legal and procedural reforms, rather than solely technological advancement. In particular, legal systems should:

establish clear and legally binding criteria for environmental harm and risk;

define the procedural status and admissibility conditions of environmental control materials;

standardize the role and methodology of expert involvement;

ensure continuity and traceability across all stages of the evidentiary process.

Implementing these measures would reduce the risk of evidentiary inadmissibility and enhance the reliability of judicial outcomes in environmental cases.

6.5. Position within existing scholarship

This study contributes to bridging the gap between forensic science and legal scholarship by demonstrating that evidentiary reliability depends on the interaction between technological capabilities and legal frameworks. While existing research has emphasized advances in forensic methodologies, it has often overlooked the procedural conditions necessary for transforming such advances into admissible evidence. Conversely, legal scholarship has not sufficiently addressed the methodological structure of forensic support.

By integrating these perspectives, the present study advances an interdisciplinary understanding of forensic support as a legally structured process of knowledge validation. This approach aligns with contemporary research emphasizing the importance of standardization, reproducibility, and interpretative control in ensuring evidentiary value across forensic domains.

6.6. Summary of discussion

The discussion confirms that forensic support in environmental crime investigations operates as a system governed by identifiable regulatory patterns, rather than as a collection of technical practices. The classification of regulatory models demonstrates that evidentiary systems differ according to how legal frameworks organize the interaction between substantive norms, procedural rules, and forensic knowledge.

These findings reinforce the conclusion that the effectiveness of forensic support depends on methodological coherence and legal integration, providing a foundation for both theoretical development and practical reform in environmental criminal law.

7. Conclusions

This study demonstrates that the effectiveness of forensic support in the investigation of environmental crimes is determined not by technological sophistication alone, but by the coherence of legal and procedural frameworks governing evidence. Through a comparative doctrinal analysis of Ukraine, Poland, Germany, and France, the research shows that evidentiary reliability depends on the structured interaction between substantive environmental norms, procedural rules, and the regulation of specialized knowledge. The proposed analytical matrix and coding procedure provide a transparent and reproducible basis for identifying regulatory models, thereby strengthening methodological rigor in comparative legal research.

The identification of three regulatory models—code-centric, regulatory-integrated, and combined—highlights that differences between legal systems are primarily structural. These models reveal how evidentiary processes are organized, how environmental data are transformed into admissible proof, and where systemic vulnerabilities arise. In particular, unclear definitions of environmental harm, ambiguous procedural status of control materials, and fragmented regulation of expert involvement remain key obstacles to effective enforcement.

From a policy perspective, the findings underscore the need for targeted legal reforms aimed at strengthening evidentiary systems in environmental crime proceedings. Legislators should prioritize the clarification of harm and risk criteria, the formalization of procedural rules governing environmental monitoring data, and the standardization of expert methodologies. Equally important is ensuring the continuity and traceability of evidence across all stages of the evidentiary process.

At the supranational level, European Union law plays a catalytic role by establishing performance-based requirements for proof and traceability, while preserving national procedural autonomy. This places responsibility on domestic legal systems to translate these standards into operationally coherent evidentiary frameworks. Strengthening such coherence is essential for enhancing the credibility, consistency, and overall effectiveness of environmental criminal enforcement.

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