

# Forensic Science and Sustainable Development: Bridging Justice and Environmental Responsibility

Aishwarya Kanwar<sup>1</sup>, Simran Gill<sup>1</sup>, Aishwarya Aneja<sup>1</sup>

<sup>1</sup> School of Law, CT University Ludhiana Punjab, India

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## Abstract:

Forensic science, traditionally focused on criminal investigation and justice, plays an evolving role in addressing modern global challenges such as environmental sustainability. This paper explores how forensic methodologies can contribute to sustainable development by investigating environmental crimes, enhancing regulatory compliance, and promoting corporate responsibility. Through the integration of advanced forensic techniques—like environmental forensics, trace analysis, and digital surveillance—justice systems can identify and mitigate environmental violations more effectively. The intersection of forensic science with environmental responsibility ensures accountability while fostering sustainable practices. This approach not only strengthens legal frameworks but also aligns criminal justice with global sustainability goals, ultimately bridging the gap between justice and environmental stewardship.

Key areas of innovation include energy-efficient laboratories powered by renewable resources, the use of biodegradable and recyclable materials for evidence handling, and the adoption of environmentally safe chemicals in analytical processes such as toxicology and fingerprinting. Sustainable crime scene management practices, such as digital documentation, further reduce the reliance on paper and physical storage, minimizing resource consumption.

Moreover, forensic science plays a crucial role in combating environmental crimes, including illegal waste disposal, poaching, and wildlife trafficking. Advanced technologies like remote sensing, Geographic Information Systems (GIS), and artificial intelligence (AI) enhance the ability to monitor environmental damage and detect illegal activities, often reducing the need for extensive field investigations. Case studies demonstrate the successful implementation of ISO 14001 standards in forensic labs, illustrating the practical benefits of green initiatives. Despite challenges, such as balancing the need for sustainability with the precision required in forensic analysis, there is a growing consensus on the importance of developing global policies and standards to support this transition. By embracing environmentally conscious practices, forensic science not only enhances its operational efficiency but also aligns with global sustainability goals, contributing to a more responsible and just society.

**Keywords:** Forensic Science, Sustainable Development, Environmental Forensics, Eco-friendly Practices, Ecological Justice, Quality

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## Introduction

Forensic science plays a crucial role in the administration of justice, providing essential evidence to support criminal investigations and legal proceedings. However, the impact of forensic science extends beyond the realm of criminal justice, as it can also contribute to sustainable development and environmental responsibility. Forensic science is an essential service in supporting criminal

investigations and the justice system. It also has global humanitarian, peace and security dimensions making it a key factor in achieving several United Nations Sustainable Development Goals. Despite forensic science's universal value, many jurisdictions are at a stark disadvantage in the continued development of forensic science with limitations in resourcing and technological capabilities. We argue that the sustainable provision of forensic science must become a critical element of future international discourse. The intersection between forensic science and sustainable development, highlighting how these fields can work in tandem to achieve justice and environmental stewardship. As the world faces mounting environmental challenges, including climate change, biodiversity loss, pollution, and resource depletion, forensic science emerges as a vital tool for promoting accountability and sustainable practices.

The integration of forensic science with sustainable development can facilitate the identification and prosecution of environmental crimes such as illegal wildlife trafficking, deforestation, and hazardous waste dumping. For instance, wildlife forensics employs techniques like DNA analysis to combat poaching and protect endangered species (Ogden & Linacre, 2015). Similarly, forensic chemistry and toxicology can detect pollutants and contaminants, ensuring industrial compliance with environmental standards (Aguirre, 2020). Furthermore, the adoption of eco-friendly practices in forensic laboratories, such as the use of sustainable materials for evidence collection and renewable energy sources, aligns with global sustainability goals outlined in the United Nations Sustainable Development Goals (UN SDGs).

This research paper delves into the nexus between forensic science and sustainable development, emphasizing the role of innovative technologies, eco-conscious practices, and collaborative efforts in bridging justice and environmental stewardship. By integrating the principles of forensic science with sustainable practices, we can address pressing environmental issues, enforce regulations effectively, and contribute to a more equitable and sustainable future for all.

### **1. The Limitations of Forensic Science: Addressing Biases and Systematic Issues**

One of the primary challenges in the field of forensic science is the recognition of its underlying limitations. Many forensic techniques rely on subjective interpretations by practitioners, leading to concerns about the validity and reliability of the evidence presented in court (Dror, 2018). Techniques such as fingerprint analysis, hair comparison, and bite mark identification, while widely used, have come under scrutiny for their potential susceptibility to human error and cognitive bias. These biases may arise from various sources, including confirmation bias, where forensic examiners unintentionally interpret evidence in a manner that aligns with investigators' or prosecutors' expectations (Dror & Hampikian, 2011).

Another significant issue is the lack of standardization and regulation across forensic practices. While some disciplines, like DNA analysis, benefit from rigorous scientific validation and standard operating procedures, others lack robust empirical testing or agreed-upon methodologies. This disparity undermines the credibility of forensic evidence and poses challenges in ensuring consistency across cases and jurisdictions (Garrett, 2011).

The problem is further compounded by inadequate funding and resource constraints in forensic laboratories. Backlogs of unprocessed evidence, outdated equipment, and insufficient training for

forensic professionals often lead to delays in justice and the potential mishandling of evidence. Additionally, the increasing reliance on forensic science in criminal investigations has not always been matched by proportional investments in research and development to improve techniques and minimize errors (NAS, 2009).

Legal frameworks also contribute to systemic issues within forensic science. Courts often lack the expertise to critically evaluate forensic evidence, leading to the admissibility of questionable or unreliable techniques. For example, in cases like *Daubert v. Merrell Dow Pharmaceuticals, Inc.* (1993), the U.S. Supreme Court set guidelines for the admissibility of expert testimony, but the application of these standards remains inconsistent. This highlights the need for greater judicial training and the inclusion of independent scientific panels to assess the reliability of forensic methods.

Addressing these limitations requires a multi-pronged approach. First, forensic disciplines should prioritize the development and adoption of objective, data-driven methods that reduce reliance on subjective interpretation. For instance, integrating artificial intelligence and machine learning tools can help automate and standardize pattern recognition tasks, such as fingerprint matching or facial recognition. Second, forensic laboratories must receive adequate funding to upgrade infrastructure, train personnel, and conduct research to validate forensic techniques. Third, fostering transparency and accountability within the field is crucial. Independent audits, quality control measures, and adherence to international standards can help restore public trust in forensic science.

Lastly, collaboration between scientists, legal professionals, and policymakers is essential to create a balanced system that recognizes the limitations of forensic science while leveraging its strengths. By addressing biases and systemic issues, forensic science can evolve into a more reliable and equitable tool in the pursuit of justice.

### **1.1 Systemic Challenges in Forensic Laboratories**

Forensic laboratories are essential in the criminal justice system, providing scientific evidence to support investigations and prosecutions. However, systemic challenges within these labs hinder their efficiency, accuracy, and overall credibility. Addressing these issues is crucial to ensuring justice and maintaining public trust in forensic science.

#### **1. Resource Constraints**

One of the most significant challenges faced by forensic laboratories is the lack of adequate resources. Many labs operate with limited funding, which affects their ability to purchase advanced equipment, maintain infrastructure, and retain skilled personnel. For example, sophisticated tools like DNA sequencers, digital forensic software, and high-performance chromatography systems are critical for accurate results, but their high costs often make them inaccessible to underfunded laboratories. This resource gap can lead to delays in processing evidence and, in extreme cases, result in errors that may impact legal outcomes.

#### **2. Case Backlog**

Forensic Backlogs not only delay justice for victims and accused individuals but can also lead to the degradation of perishable evidence, rendering it unusable. In high-profile cases, the pressure to expedite results may result in rushed or incomplete analyses, further jeopardizing the quality of forensic evidence. The volume of cases often exceeds the capacity of forensic professionals, leading to delays in evidence analysis and reporting. DNA evidence, in particular, is prone to backlogs due to its time-intensive processing and high demand in criminal cases.

### 3. Inadequate Training and Expertise

The expertise and skill of forensic scientists are critical to the field's excellence. Regretfully, it can be difficult for many forensic labs to find and keep skilled workers. A lack of standardized training programs and continuing education opportunities further exacerbates the issue. For instance, mislabelling samples, contamination during evidence handling, or incorrect data interpretation can compromise the integrity of forensic findings. In court, where the reliability of expert witnesses is essential, this becomes more difficult.

### 4. Impact on Justice and Public confidence

Public confidence in forensic laboratories is also at risk when cases of negligence or misconduct come to light. Errors in forensic analysis have the potential to erode the validity of evidence in court and raise questions about the overall dependability of forensic science. High-profile errors, such as misidentified DNA samples or false testimony by forensic experts, erode trust in the justice system and highlight the urgent need for reform. Longer legal proceedings and incorrect convictions or acquittals can result from delays in the processing of evidence which leads to systemic challenges have far-reaching implications for the criminal justice system.

## 2. Assuring Quality in sustainable forensic science service provision

Quality management (QM) systems based on competency-based standards such as ISO/IEC 17025 have been developed, implemented, and adopted by numerous forensic science facilities worldwide. Independent recognition of compliance with these standards via accreditation has become mandatory in certain jurisdictions. The process of independent expert assessment for accreditation purposes has been argued as critical to ensuring minimum standards are met. For forensic science to operate as a global endeavour where borders are no longer a barrier to intelligence-led investigation of crime, harmonisation of the information being shared and the quality systems used to produce it is key. However, there are issues associated with the accreditation process that must be considered, particularly when assessing the value of this process in the context of sustainable service provision for facilities challenged by remote geography, limited access to peak technology or restricted budgetary support. In addition to innovation and improvement of protocols, the key to overcoming such challenges hinges on demand from within the field itself, coupled with the necessary political support. Within the principles of sustainable practice, we need to look beyond a 'one-size-fits-all' approach to accreditation as the sole answer to achieving this goal.

### **Continuous Quality Improvement**

Forensic science is a constantly evolving field that requires ongoing assessment and refinement of methodologies to maintain accuracy and reliability. Regular quality control measures, proficiency testing, and accreditation processes can help ensure that forensic practices remain scientifically sound. Organizations such as the National Institute of Standards and Technology (NIST) and the Organization of Scientific Area Committees (OSAC) for Forensic Science provide guidelines for improving forensic methodologies. Implementing continuous quality improvement (CQI) strategies can enhance the reproducibility of forensic results, thereby increasing their admissibility in court proceedings (Kass et al., 2019).

### **Transparency and Accountability**

Public trust in forensic science is crucial, particularly given its role in the criminal justice system. Transparency in methodologies, data-sharing, and validation studies can help ensure that forensic conclusions are based on sound scientific principles. The National Academy of Sciences (NAS) has recommended that forensic disciplines adopt more open scientific practices, such as publishing validation studies and allowing peer review (National Research Council, 2009). Ensuring accountability through oversight mechanisms, such as forensic science commissions or independent audits, can help prevent errors and wrongful convictions.

### **Collaboration and Knowledge-Sharing**

Forensic science benefits greatly from interdisciplinary collaboration and knowledge-sharing. By fostering partnerships between forensic laboratories, academic institutions, and law enforcement agencies, experts can share best practices, develop new analytical techniques, and standardize protocols. International cooperation is also essential, as criminal activities often transcend borders, requiring forensic scientists to collaborate on cases involving cybercrime, terrorism, and human trafficking (Houck & Siegel, 2015). Open-access forensic databases, professional organizations, and conferences play a crucial role in facilitating this exchange of knowledge.

### **Investing in Research and Development**

To keep pace with emerging threats and advancements in technology, forensic science must continuously invest in research and development. Innovations in DNA analysis, artificial intelligence, and digital forensics have significantly improved the accuracy and efficiency of forensic investigations. Funding agencies such as the National Institute of Justice (NIJ) support research initiatives aimed at developing new forensic techniques and improving existing ones. Without sustained investment, forensic science risks falling behind, potentially compromising the integrity of criminal investigations and the judicial process.

## **3. The Future of Forensic Science: Moving Toward a Sustainable-Based Approach**

The field is facing growing concerns over its environmental impact due to the extensive use of non-biodegradable materials, energy-intensive laboratory procedures, and chemical waste. The transition to a sustainable-based approach in forensic science involves adopting eco-friendly practices, reducing the carbon footprint of forensic investigations, and integrating sustainable technologies. The current

environmental challenges within forensic science and proposes solutions such as green chemistry, digital forensics, and eco-friendly packaging for evidence collection. and it also highlights in making forensic science more sustainable.

Forensic analysis often involves the use of hazardous chemicals, such as organic solvents and reagents, which generate toxic waste. Forensic laboratories operate high-energy-consuming instruments such as gas chromatography-mass spectrometry (GC-MS), DNA sequencers, and electron microscopes. These devices require continuous operation and contribute to a high carbon footprint. The Evidence collection and storage rely on single-use plastic bags, gloves, swabs, and containers, which contribute to plastic pollution. The limited availability of sustainable alternatives has made it difficult to transition away from these materials.

To mitigate environmental harm, forensic science must incorporate sustainable practices. Several key initiatives can drive this transformation:

### 3.1 Adoption of Green Chemistry

Green chemistry principles emphasize the reduction of hazardous substances in forensic analysis. Researchers are developing bio-based solvents and non-toxic reagents for forensic applications (Anastas & Zimmerman, 2019).

### 3.2 Digital and AI-Based Forensics

The shift to digital forensic investigations, including cybercrime analysis, minimizes the need for physical evidence processing. AI and machine learning applications also reduce the reliance on chemical-based forensic methods (Liu et al., 2022).

### 3.3 Energy-Efficient Laboratories

Forensic labs can adopt energy-efficient equipment, implement renewable energy sources, and improve waste management systems to reduce their environmental impact (Jones et al., 2021).

### 3.4 Biodegradable Evidence Packaging

Using biodegradable or recycled materials for evidence collection and storage can significantly reduce plastic waste. Recent innovations include plant-based plastic alternatives and reusable forensic tools (Williams & Patel, 2023).

### 3.5 Sustainable Crime Scene Investigation

Crime scene units can adopt sustainable methods, such as eco-friendly fingerprint powders, reusable gloves, and energy-efficient lighting. Research suggests that natural-based powders derived from plant extracts can replace synthetic fingerprint dusting powders (Fernandez et al., 2020).

## 4. Conclusion

Forensic science plays a crucial role in promoting justice, security, and the rule of law, making it an essential component of sustainable development. However, the field faces several systemic challenges that hinder its effectiveness and long-term sustainability. These challenges include inconsistent standards across forensic laboratories, limited funding for research and development, outdated

methodologies, and a lack of collaboration among forensic experts globally. Additionally, environmental concerns related to forensic waste disposal and the energy-intensive nature of some forensic processes pose further obstacles to sustainability.

To address these challenges, there is an urgent need for quality improvement methods that enhance the reliability, accuracy, and efficiency of forensic science. Implementing continuous quality improvement (CQI) strategies—such as standardized protocols, accreditation programs, and independent auditing—can help maintain scientific rigor and ensure that forensic evidence withstands legal scrutiny. Furthermore, investment in emerging technologies like artificial intelligence, automation, and green forensic methods can reduce resource consumption and improve the efficiency of forensic investigations.

Sustainable forensic practices, including responsible waste management, digital forensics to minimize physical sample use, and energy-efficient laboratory operations, must become a priority. Governments, academic institutions, and forensic laboratories should collaborate to establish policies that integrate sustainability principles into forensic science while maintaining high standards of accuracy and reliability.

Ultimately, overcoming systemic challenges and adopting quality improvement measures are essential for the long-term sustainability of forensic science. A robust and ethically sound forensic system not only strengthens the justice system but also supports broader sustainable development goals by ensuring fair trials, protecting human rights, and advancing scientific progress.

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