

Civil Liability Arising from Environmental Pollution Damage in the Digital Transformation: A National and International Legislative Perspective

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Abstract

The digital transformation has created unprecedented legal challenges in the area of civil liability for environmental pollution damage, as reliance on digital systems and predictive artificial intelligence technologies has become a key element in managing polluting activities and monitoring environmental risks. However, this new reality raises delicate issues concerning the determination of the basis of liability, the attribution of fault, the proof of causality, and the formulation of mechanisms for assessing compensation for environmental damage in a complex digital environment. This paper aims to analyse the extent to which traditional rules of civil liability can accommodate these changes, while proposing advanced legislative mechanisms that ensure effective protection of the environment without hindering digital innovation.

Keywords: Civil Liability, Environmental Pollution, Digital Transformation, Compensation, Artificial Intelligence.

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Introduction

The world today is witnessing profound transformations in both the environmental and technological spheres, with digital transformation becoming an integral part of the lives of individuals and institutions. These transformations have altered the nature of environmental damage and the mechanisms for monitoring it, creating complex challenges for civil law in determining liability for environmental pollution damage. Modern digital technologies, such as satellites, smart sensors, and big data analytics, have enabled unprecedentedly precise monitoring of emissions and pollution; however, they have simultaneously raised new legal questions regarding proving damage, identifying the responsible party, and assessing fair and sustainable compensation, as in cases of cyber breaches of industrial monitoring systems. (OECD, Digital Technologies for Environmental Policy: Tools and Applications, OECD Publishing, 2020).

This study examines the environmental responsibility of individuals and companies in the digital age, focusing on how traditional principles of civil liability can be adapted to the specificities of digital environmental damage, such as the electronic leakage of contaminated data or the remote monitoring of industrial pollution. It also seeks to explore national legislative frameworks. (Law 03-10 of July 19, 2003, relating to the protection of the environment within the framework of sustainable development, No. 43, p. 6.)

Internationally, and mechanisms for developing civil compensation to ensure environmental protection and achieve balanced justice between affected parties. (Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, 1989, p. 57)

In this context, a central question arises regarding how traditional principles of civil liability, as applied in Algerian civil law and international environmental instruments, can be adapted to the specificities of environmental damage resulting from digital activities.

While digital technologies are developing more precise monitoring and analysis mechanisms, legal frameworks often remain geared towards traditional models of damage. This raises a debate about the

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adequacy of these frameworks in proving damage, assigning responsibility to the actual perpetrator, and determining fair and sustainable compensation that not only addresses the individual's material needs but also incorporates environmental and ecological considerations. (Kamal Misbah, 2025, pp. 747-760.)

Hence, the central problem addressed in this research paper is formulated in the following question:

If traditional frameworks for civil liability in Algerian civil law and international environmental frameworks focus on models of direct and tangible material damage, how can these frameworks adapt to accommodate invisible, multi-stage, and delayed digital environmental damages, ensuring the precise identification of the responsible party and a fair and sustainable assessment of compensation that extends beyond material redress to include environmental and ecological considerations?

From this perspective, this study first reviews the national and international legislative frameworks for environmental protection before analyzing the impact of digital transformation on mechanisms for proving damage and civil liability, with a focus on the practical challenges associated with digital monitoring and compensation for environmental damages.

Section One: Traditional Frameworks for Civil Liability for Environmental Damage

Civil liability is the traditional framework for addressing environmental damage, initially based on general rules of fault and liability, despite the difficulty of adapting them to the specific nature of environmental damage. (Ordonnance n° 75-58, contenant le Code civil, tel que modifié et complété, article 124.) En Algérie, le droit civil est la principale référence pour l'indemnisation de ces dommages ; cependant, son application révèle ses limites face à la nature collective et complexe des dommages environnementaux. (Kamal Misbah, "Environmental Damage in Algerian Legislation", previous reference.) At the international level, liability rules have evolved through the adoption of principles such as "polluter pays" and the conclusion of special agreements, particularly in the areas of hazardous waste and transboundary pollution. (It is based on the "polluter pays" principle as adopted in the European Community Council Directives of the 1970s (68/81 EEC), and subsequently enshrined in Principle 16 of the Rio Declaration of 1992; on the Basel Convention on the Control of Hazardous Wastes, 1989, ratified by Algeria in 1994; and on the draft principles of the International Law Commission (ILC) on international responsibility for environmental damage submitted to the General Assembly in 2006.) However, these frameworks still suffer from limited effectiveness and enforcement. Therefore, this section addresses civil liability in Algerian law (first section) and international frameworks relating to compensation (second section).

Section 1: Civil Liability in Algerian Civil Law for Environmental Damage

This section lays the groundwork for an analysis of the traditional frameworks for civil liability for environmental damage in Algerian civil law, starting with the general principles of tort liability and liability for hazardous activity. It then highlights the challenges these frameworks face given the indirect and delayed nature of environmental damage, before addressing Environmental Protection Law No. 03-10 and the mechanisms for promoting fair compensation and environmental redress.

First: The Traditional Foundations of Tort Liability and Liability for Hazardous Activity.

Civil liability, in its traditional framework, rests on two main foundations: tort liability based on fault, and liability for hazardous activity, or liability based on strict liability. Together, these form the classic framework for compensating damages, including environmental damage.

1- Tort Liability Based on Fault: This is the general principle in civil law, whereby anyone who commits a fault that causes harm to another is obligated to compensate them, provided the elements of fault, harm, and causation are present. This foundation is supported by Article 124 of the Algerian Civil Code, which stipulates that any act committed by a person that causes harm to another obligates the person responsible to provide compensation. However, this foundation faces several obstacles in the environmental field,

particularly regarding proving fault and identifying the perpetrator in cases of complex or multi-source pollution.

2- Liability for Hazardous Activity: This represents an evolution from the traditional foundation based on fault, as it is based on the concept of strict liability without requiring proof of fault, when the activity inherently involves specific risks. This is based on the rules of liability for things or custody, which stipulate that a person is liable for damages resulting from their activity or from things under their custody. (Abdul Razzaq Ahmed Al-Sanhuri, p. 799 and following.)

This basis is more suitable for environmental damage, given its frequent association with hazardous industrial or technological activities, thus facilitating compensation for the affected party without the burden of proving fault.

Despite the importance of these two principles, their application remains limited in the face of the unique nature of environmental damage. This has led to the search for modern mechanisms based on prevention, insurance, and compensation funds to enhance the effectiveness of fair compensation and environmental redress.

Second: Challenges of Traditional Frameworks in Addressing Indirect and Delayed Environmental Damage

Traditional frameworks of civil liability face serious difficulties when applied to indirect and delayed environmental damage due to its unique characteristics, which transcend the classical model based on direct and immediate individual harm. These challenges manifest in three main patterns:

1- Collective Harm of Environmental Damage

Environmental damage is often characterized as collective harm affecting environmental elements as a shared interest (such as air, water, and biodiversity), rather than merely a specific individual interest. This makes it difficult to determine the status of the affected party entitled to compensation under traditional rules that require direct and personal harm. (Mustafa Kamal Taha, 2009, p. 112.) This character also raises the issue of representing the collective interest before the courts, and the limits of accepting lawsuits filed by associations or public bodies.

1- Weakness of Evidence and Difficulty of Proof

The issue of proof is one of the most significant challenges, especially concerning establishing a causal link between harmful activity and environmental damage. This is due to the complexity and multiplicity of pollution sources and the nature of damage that may only appear after a long period. Often, the damage results from the accumulation or interaction of multiple factors, making the application of traditional rules of evidence based on certainty extremely difficult. This has led some legal systems to adopt legal presumptions or to reduce the burden of proof in environmental matters.

2- The Problem of Statutes of Limitations

Delayed environmental damage poses a real problem concerning statutes of limitations, as the damage may not become apparent until many years after the harmful act occurred. This is known as late damage, as is the case with industrial or radioactive pollution. Under traditional rules that begin calculating the statute of limitations from the date of the act or the date of knowledge of it, the affected party may be deprived of their right to claim compensation due to the expiration of the legal period. (Philippe Sands and Jacqueline Peel, 2018, p. 742.)

Therefore, modern jurisprudential and legislative trends have emerged calling for adapting statutes of limitations to suit the specific nature and characteristics of environmental damage.

Accordingly, it is clear that traditional frameworks, despite their importance, often fail to effectively address the specificities of indirect and delayed environmental damage, necessitating the development of more flexible and appropriate legal rules. (Muhammad Hussein Mansour, 2008, p. 67.)

Section Three: Environmental Protection Law No. 03-10 and its Mechanisms for Promoting Fair Compensation and Environmental Reparation

Law No. 03-10 of July 19, 2003, concerning environmental protection within the framework of sustainable development, constitutes the fundamental legislative framework in Algeria for promoting environmental protection. It was enacted to address the shortcomings of traditional rules of civil liability, particularly with regard to achieving fair compensation and environmental reparation.

First: Establishing the Principle of Compensation for Environmental Damage

The law establishes the principle of liability for anyone who causes environmental damage, obligating them to repair or compensate for the damage, whether direct or indirect. It also broadens the scope of protection to include environmental elements as a collective interest, not just individual rights, which represents a significant development compared to traditional rules. (Article 4 of Law No. 03-10 relating to the protection of the environment within the framework of sustainable development)

Second: Adopting the "Polluter Pays" Principle

The Algerian legislator enshrined the "polluter pays" principle as a fundamental mechanism to ensure fair compensation. Under this principle, the polluter bears the full costs of repairing the damage and restoring the environment to its state before the pollution occurred, including the costs of prevention and minimizing future damage. This principle aims to achieve environmental justice and strengthen deterrence against environmentally harmful behaviors by placing the responsibility for the resulting costs directly on the polluter, not on society or the state.

Third: Prioritizing in-kind Compensation (environmental restoration)

The law did not limit itself to monetary compensation, but rather gave special priority to rehabilitating the damaged environment through what is known as in-kind compensation. This involves the responsible party taking the necessary measures to repair the environmental damage and restore ecological balance. This approach is more appropriate to the nature of environmental damage, which often cannot be fully remedied by financial compensation alone, but rather requires intervention to restore the ecosystem to the greatest extent possible.

Fourth: Institutional Mechanisms and Enhanced Oversight

Law No. 03-10 established a comprehensive institutional and oversight system dedicated to environmental protection and monitoring resulting damage. It assigned specific tasks to specialized bodies, such as environmental agencies and relevant technical and administrative departments, responsible for the continuous monitoring of the environment, data collection, and assessment of pollution levels and sources. The role of these bodies extends beyond oversight to include the preparation of scientific studies and technical reports, particularly impact studies, which are essential tools for estimating the extent of environmental damage and identifying its direct and indirect effects.

These mechanisms also contribute to supporting the judiciary and administrative bodies with the necessary technical expertise by providing accurate reports that help prove environmental damage and establish causation, thus mitigating the difficulties of proof inherent in this type of damage. This enhances the effectiveness of compensation, whether through a fairer financial assessment or by directing the responsible party to take appropriate remedial measures (in-kind compensation), thereby contributing to restoring environmental balance as much as possible. Therefore, the scientific and technical character that these mechanisms add to the process of assessing environmental damage is a fundamental guarantee for achieving

transparency and accuracy in estimating compensation, and represents a qualitative leap compared to the traditional reliance on classical means of proof.

Fifth: The Role of Prevention in Supporting Compensation

Law No. 03-10 adopted a preventive approach that is considered the cornerstone of the environmental protection system. This is achieved by obligating project owners and those undertaking activities with a potential impact on the environment to conduct environmental impact studies before obtaining a license. These studies serve as a proactive tool for assessing environmental risks and identifying their effects before implementation begins. (Law No. 03-10 relating to the protection of the environment within the framework of sustainable development, previous reference, p. 6.)

These studies are not limited to describing the project alone, but also include a precise scientific analysis of its potential effects on various elements of the environment, along with proposing preventive, mitigating, or compensatory measures for the expected damages.

This mechanism also contributes to integrating the environmental dimension into the administrative decision-making process. Licenses are granted only after ensuring the project's ability to integrate with its surrounding environment without causing significant harm, thus reducing the likelihood of damage in the first place. This aligns with the precautionary principles of environmental law.

Furthermore, impact studies are particularly important in the field of liability and compensation. They serve as a reference document that can be consulted in the future to determine the extent to which the project owner has adhered to preventive measures, identify any shortcomings, and help establish a causal link between the activity and the environmental damage. Therefore, these studies not only play a preventive role but also facilitate dispute resolution and enhance the effectiveness of compensation, whether through monetary compensation, in-kind reparations, or remedial measures.

The Second Requirement: International Frameworks for Liability and Compensation for Environmental Damage

The topic of international frameworks for liability and compensation for environmental damage is one of the most important aspects of the development of international environmental law, given the wide scope and complexity of transboundary damage, and the emergence of a series of agreements and principles that seek to establish effective mechanisms to ensure redress and compensation for those affected at the international level.

Section 1: The Basel Convention and Liability for Compensation for Environmental Damage from Hazardous Activities

The Basel Convention, specifically its Protocol on Liability and Compensation for Damage Caused by Transboundary Movements of Hazardous Wastes and their Disposal, is one of the most prominent international frameworks regulating liability for compensation for environmental damage resulting from hazardous activities related to hazardous wastes and transboundary activities. (Basel Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements of Hazardous Wastes, 1999.)

The agreement places strict liability on the responsible party (waste producer, transporter, or collector) for environmental damage, subjecting compensation to a system of financial and insurance mechanisms, setting statutes of limitations, and linking compensation to the restoration of the environmental condition as much as possible. This embodies a modern approach that combines liability, compensation, and in-kind redress in the field of hazardous activities. (Naeem Shawish, Hamza Heba, 2023, pp. 246-265.)

Section Two: Legal Principles of Liability and Compensation in International Environmental Agreements

The legal principles in this area can be summarized in two main points. (Adel Amer, 2015, p. 118 and beyond.)

First: Responsibility for Hazardous Activity in International Environmental Instruments

The principle of responsibility for hazardous activity is one of the fundamental pillars in international frameworks for responsibility and compensation for environmental damage, especially in the field of high-risk transboundary activities. In international environmental instruments, it is an objective responsibility that does not require proving fault. Rather, the existence of a hazardous activity that causes environmental damage is sufficient to hold the responsible party liable for compensation, even with adherence to the highest safety standards, based on the idea that the benefit from the activity must be accompanied by bearing its risks, especially in transboundary environmental damages that are borne by the owner of the activity and not by the affected society or state.

Second: Environmental Compensation

Environmental compensation is a cornerstone of the system of liability for environmental damage in international instruments. It goes beyond traditional compensation for personal and material damages to encompass the environment itself, considered a public good deserving of protection and redress. This concept relies on various forms of compensation, including monetary compensation and its investment in environmental restoration, as well as in-kind measures (restoration to its previous state or rehabilitation of damaged ecosystems), thereby enhancing the effectiveness of the "polluter pays" principle at the international level. (Fadila Aqli, 2020, pp. 337-352.)

Third Branch: Towards Flexible Models of Liability for Environmental Damage

The evolution of liability for environmental damage, at both the national and international levels, points towards the adoption of flexible and advanced models that transcend the limitations of traditional frameworks for tort liability and liability for hazardous activity. These models address the unique nature of indirect, delayed, collective, and transboundary environmental damage. They eliminate the logic of delayed individual compensation and adopt integrated approaches that combine strict liability, automatic compensation, compensation funds, and environmental reparations. This allows for faster and more comprehensive compensation and more effective solutions for complex damages that cannot be addressed within classical legal frameworks. (Miloud Qayesh, pp. 135-141. See also: Lavanya Rajamani & Jacqueline Peel, The, 2021, pp. 512–518.)

With the continuous increase in hazardous industrial and technological activities, the need has arisen for more flexible legal systems based on the "polluter pays" principle. These systems hold the perpetrator accountable even in the absence of clear evidence of fault. Redistribution, distributed through environmental damage compensation funds or mandatory insurance schemes, provides the state and local communities with the necessary resources to cover the costs of repair and rehabilitation. These models also rely on the concept of automatic or early compensation, which allows for the provision of immediate financial compensation to beneficiaries or affected parties, even if legal investigations are ongoing or all responsible parties have not yet been identified. This mitigates the negative social and economic impacts of environmental damage.

Furthermore, these flexible models highlight environmental reparations as a fundamental element of the compensation system, not merely as an alternative to monetary compensation, but as an integrated mechanism for restoring ecological balance and reintegrating victims and communities into the affected environment through restoration programs, reforestation, and the rehabilitation of damaged ecosystems. This represents a fundamental shift in the perspective of responsibility, from compensation for the individual alone to compensation for both the individual and the environment, thereby achieving a balance between social and environmental justice, and pushing towards building a flexible and sustainable system of responsibility for environmental damage, which contributes to preventing damage, accelerating its repair, and making compensation a collective and transparent experience based on the cooperation of states, international organizations, local communities, and civil society.

Section Two: Adapting Legal Frameworks to Digital Environmental Damage

The environmental damage associated with digital transformation raises new legal challenges due to the overlap between the technological dimension and indirect environmental impacts, necessitating the adaptation of liability and compensation rules to their specific nature. This section addresses the nature of this damage on the one hand, and the need to develop modern legal frameworks to ensure effective liability and sustainable environmental redress on the other.

The first requirement: The nature of digital environmental damage between theory and reality

Defining the nature of digital environmental damage is a fundamental entry point for understanding its legal specificity, given its invisible, cumulative, and delayed nature, which is difficult to perceive within traditional frameworks. (Ahmed El-Sayed El-Daqr, 2023, p. 23.)

Therefore, it is necessary to analyze its characteristics and distinguish between theory and practice.

Section 1: The Specificities of Invisible Environmental Damage in the Digital Environment

The specificities of environmental damage in the digital environment are manifested in the diversity of its forms and the complexity of its sources. It is not limited to direct technical impacts but extends to hidden and complex patterns of risks that indirectly affect ecosystems. In this context, analyzing this damage requires examining its most prominent manifestations through the study of cyber leaks, digital monitoring, and industrial system control, as these are among the most important mechanisms that contribute to causing invisible and multi-stage environmental damage within the digital space. (Abdul Wahab Abdullah Al-Maamari, Nadine Jumaa Al-Qubailat, 2025, pp. 96-112.)

First: Cyber Leaks

Cyber leaks are among the most prominent manifestations of invisible digital environmental damage. They take the form of breaches or malfunctions affecting information systems related to natural resource management or environmentally sensitive facilities, leading to the leakage of sensitive data or the disruption of environmental monitoring and control systems. The effects of these leaks are not limited to the information sphere; they can also lead to actual environmental damage, as occurs when monitoring systems in factories or power plants are compromised, potentially resulting in uncontrolled emissions or the release of pollutants without immediate detection.

These leaks are also characterized by their intangible nature and the complexity of proving a causal link between them and environmental damage, especially with the increasing number of stakeholders involved in operating and maintaining digital systems. This creates imbalances in determining responsibility among system operators, digital service providers, and other technical parties. This situation necessitates the development of a legal framework that addresses the risks of cyber leaks by strengthening prevention mechanisms, establishing a clear definition of digital responsibility, and linking it to a broader system of environmental protection and liability for damages.

Second: Digital Monitoring

Digital monitoring represents a modern tool in environmental management, relying on remote sensing technologies, artificial intelligence, and environmental information systems to track environmental changes in real time. This enables the monitoring of pollution levels, resource consumption, and industrial emissions with increasing accuracy, supporting environmental decision-making and enhancing the efficiency of environmental monitoring.

However, the growing reliance on these technologies raises legal challenges related to the security and verifiability of digital data, as well as the risks of disruption or hacking that could compromise the accuracy of environmental information. Thus, digital monitoring combines the enhancement of environmental

protection with the introduction of new issues in legal liability. (Nabil Shaib, Lina Shatwan, 2025, pp. 15-32.)

Third: Industrial Systems Control

Controlling industrial systems is a fundamental element in ensuring compliance with environmental standards and mitigating the negative impacts of industrial activities. It relies on automated control technologies such as Industrial Control Systems (ICS) and advanced digital protocols to precisely regulate production processes. This allows for real-time monitoring of critical variables such as emissions, energy consumption, and waste management, thereby enhancing operational efficiency and reducing the risk of unintentional pollution. However, these systems face legal challenges related to digital monitoring, particularly concerning data protection from cyberattacks that could lead to malfunctions contributing to environmental incidents, thus raising issues regarding civil liability for resulting damages. (Fatima Al-Zahraa Ali Rashwan, 2025, pp. 13-98.)

Section Two: Multiple Parties Responsible in the Digital Chain

Environmental digital monitoring is characterized by multiple parties responsible within the digital chain, complicating the determination of civil liability for damages resulting from malfunctions or breaches. In this complex technological chain, the role of the system manufacturer stands out as the primary party responsible for design flaws or weak security measures, alongside the system operator, who bears responsibility for daily operation and maintenance, the data owner, responsible for protecting data from leaks, and finally, the state, as the regulatory body ensuring legislative compliance. This multiplicity creates difficulties in establishing causation and fairly distributing responsibilities, particularly in Tunisian legal contexts where current legislation lacks specific provisions for environmental digital systems. This necessitates the development of shared judicial mechanisms to overcome these complexities.

First: The producing company bears responsibility for the design and security maintenance of systems.

The producing company bears responsibility for the design and security maintenance of systems. General legal principles of tort liability obligate it to ensure the integrity of the digital product from the design stage through to post-sale, including the application of encryption standards and vulnerability testing. In the context of environmental monitoring, this obligation extends to providing periodic updates that correct defects that could lead to inaccurate environmental data, thereby exposing affected parties to harm. The company can also be sued based on the principle of manufacturing defects if it is proven that the breach resulted from fundamental technical failures. However, this liability may be mitigated if the company proves that the malfunction resulted from misuse by the system operator, highlighting the need for clear contracts that define the scope of warranties and shared responsibilities.

Second: The System Operator

The system operator has a legal and technical obligation to ensure the proper functioning of environmentally related digital systems. This includes performing routine maintenance and regularly updating software and security systems to prevent malfunctions that could lead to indirect environmental or technical damage. This obligation is an application of the principle of due diligence in managing hazardous activities, extending to the prevention of potential risks arising from negligence or technical mismanagement. The system operator is also legally liable for damages resulting from human error or failure to update security systems, particularly when this leads to the disruption of environmental monitoring or control systems or causes environmental imbalances. The scope of this liability is amplified when dealing with sensitive digital systems that require a high level of professionalism and technical vigilance. (Ahmed El-Sayed El-Daqqn, previous reference, p. 88.)

Therefore, this trend reflects a growing emphasis on proactive digital responsibility, ensuring the mitigation of risks before they occur and strengthening the foundations of sustainable digital governance.

Third: The Data Owner's Contribution to Maintaining System Integrity

The scope of environmental digital responsibility extends to the data owner as a fundamental pillar, alongside the operator's obligations for proper maintenance and operation. The data owner is obligated to ensure data accuracy and protect it from distortion or leakage. Poor data management can disrupt environmental monitoring and lead to indirect damages, such as uncontrolled emissions or the failure of smart alarm systems. This is particularly important in ensuring compliance with encryption standards and authorized access. The data owner is required to implement rigorous technical measures to prevent leaks and precisely define permissions to avoid unauthorized access. Any failure to meet these standards could jeopardize ecosystems, leading to falsified data that contributes to indirect environmental damage. This constitutes an integration in digital governance that requires proactive coordination between actors, reinforced by the principles of sustainable digital governance in modern legislation.

Fourth: State Responsibility

The state bears comprehensive regulatory responsibility through mandatory legislation and compliance monitoring. Laws are issued that define standards for digital environmental monitoring and require facilities to submit periodic reports on system performance and security procedures. The state also oversees licensing mechanisms and field inspections to ensure the implementation of preventative measures against breaches or malfunctions. It can be held legally accountable for failing to impose strict penalties or update legislation to keep pace with technological advancements. In cases of regulatory failure, such as the lack of standardized security protocols, those affected can resort to the principle of administrative liability for indirect damages resulting from inaccurate environmental data. This creates a multi-layered legal framework that requires sophisticated evidentiary mechanisms, such as joint investigations or technical experts, to distribute responsibilities between the state and the private sector in a fair and effective manner. (Abdul Qader Nasser, December 2025, pp. 225-245.)

Third Section: The Impact of These Characteristics on Proving Damage and Determining Causation

The unique characteristics of digital environmental damage—its invisible nature, multi-stage processes, and the interconnectedness of actors—directly impact the issue of proving damage and determining causation. Traditional rules of evidence are no longer adequate to accommodate this new type of damage. The absence of direct physical impact and the difficulty of tracing the source of the malfunction within complex digital systems make proving environmental damage a technical and legal process simultaneously, relying more on digital expertise and data analysis than on classical methods of proof. Furthermore, the multiplicity of actors involved in the digital chain—from system operators to service providers and data owners—creates an overlap of roles, making it difficult to attribute damage to a specific actor and weakening the possibility of proving direct causation. This complexity is compounded by the cumulative and delayed nature of digital environmental damage, where the damage does not appear immediately but rather develops gradually as a result of a series of interconnected technical processes, thus opening the door to multiple possible sources of the damage.

Therefore, these particularities necessitate a reconsideration of traditional rules of evidence, by enhancing the role of digital technical expertise, adopting flexible legal presumptions, and developing approaches based on probabilistic causation or contribution to causing harm instead of strict direct causation, in order to ensure greater effectiveness in protecting the digital environment and achieving compensatory justice.

The Second Requirement: Developing Legal Frameworks to Ensure Fair and Sustainable Liability and Compensation

Given the challenges arising from the complexities of digital environmental monitoring and the multiplicity of responsible parties, there is an urgent need to develop modern legal frameworks that guarantee a fair distribution of responsibilities and sustainable compensation that keeps pace with technological advancements. These frameworks must strengthen digital evidence mechanisms and adopt the principles of probabilistic causation to address invisible damages, thereby enabling environmental protection in the digital economy. (Abdul Wahab Abdullah Al-Maamari, previous reference.)

Section One: Adapting the Principles of Civil Liability

Traditional principles of civil liability must be adapted to the specificities of the digital environment. This involves broadening the concept of fault to include technical and organizational shortcomings and adopting strict liability in cases of damage resulting from malfunctions in smart systems. It also requires redefining causation to become probable rather than direct, relying on digital expertise as a primary source of evidence to ensure effective compensation for those affected by invisible pollution. In this way, liability transforms from a corrective reaction into a sustainable preventative mechanism that strengthens environmental governance in the age of digital monitoring.

First: Liability for Hazardous Activity

Liability for hazardous activity represents a significant development in civil liability, shifting from a fault-based approach to an objective one based on liability. It suffices to prove the occurrence of the damage and its connection to the hazardous activity, without requiring proof of fault. This approach is justified by the fact that some activities inherently involve exceptional risks that must be borne by those who undertake and benefit from them. Its importance in the environmental field is highlighted by the fact that most damage is linked to complex industrial, chemical, and technological activities whose effects are difficult to fully control. It also reduces the burden of proof on the injured party, but it raises problems related to proving causation in complex cases. Legal scholars have helped overcome this by developing concepts such as presumed or indirect causation.

Second: Explicit Liability

Explicit liability is one of the most important developments in modern civil liability. It is based on the legislator establishing a specific liability through a clear legal text that outlines its conditions and effects without the need to refer to general rules. This is often an objective or presumed liability based on the principle of bearing responsibility rather than proving fault, thus reducing the burden on the injured party and facilitating the compensation process. This approach reflects the legislator's desire to adapt civil liability to the nature of contemporary damages, particularly environmental and digital damages, which are characterized by complexity and difficulty in proving them. (Abd al-Razzaq Ahmad al-Sanhuri, *The Mediator in Explaining the New Civil Law*, p. 805 and following.)

Third: Mitigated Liability

This is a form of civil liability where the legislator or the judiciary decides to reduce the burden of proof or the scope of compensation compared to general rules, without completely abolishing liability or transforming it into strict liability. It is based on modifying one of the elements of liability or lessening its severity, such as reducing the burden of proving fault or narrowing the conditions of causation, taking into account the specific nature of certain activities or the positions of those harmed. This type of liability aims to achieve a balance between protecting the injured party and not overburdening the liable party with full consequences that may not be commensurate with the nature of the act or activity, as seen in some forms of professional liability or liability arising from complex activities where full proof is difficult.

Section Two: Strengthening Mechanisms for Proving Harm in the Digital Environment

Strengthening mechanisms for proving harm in the digital environment is a fundamental challenge imposed by the evolving environmental damage associated with digital transformation. This is due to the invisible nature of this damage, the multiplicity of its sources, and the complexity of its technical infrastructure. Traditional rules of evidence, based on direct physical means, are no longer sufficient to address this type of damage. This necessitates reliance on modern methods of proof based on digital evidence, big data analysis, system logs, and artificial intelligence techniques for tracking digital environmental impact.

The role of specialized technical expertise is also crucial in helping the judiciary understand the nature of the damage and determine the causal relationship between the digital act and the environmental outcome, especially given the multiplicity of actors involved in the digital chain. In this context, some modern systems have moved towards easing the burden of proof on the affected party by adopting digital evidence and probabilistic causation, thus ensuring greater effectiveness in environmental protection and achieving compensatory justice.

Therefore, developing mechanisms for proving harm in the digital environment is no longer an option but a legal necessity dictated by the nature of contemporary harm. This ensures a balance between the difficulty of proving harm and the effectiveness of legal protection for the environment.

Third Branch: Developing Fair and Sustainable Compensation Models

The development of fair and sustainable compensation models is a natural extension of the evolution of modern environmental responsibility. Compensation is no longer limited to traditional monetary reparations but is now based on more comprehensive and effective approaches that consider the specific nature and complexities of environmental damage. This evolution aims to strike a balance between redressing damage and ensuring the continuity of economic and digital activity, while also promoting a preventative approach to addressing damage before it occurs or worsens. (See: Digital Economy Report, Overview, Shaping an Environmentally Sustainable and Inclusive Digital Future, United Nations Conference on Trade and Development, Geneva, United Nations, 2024.)

In this context, this section addresses the most important mechanisms that embody this transformation. It examines environmental compensation as a priority based on rehabilitating the damaged environment, environmental insurance as a financial tool to guarantee coverage for damages, guarantees as a legal means to obligate actors to bear potential financial responsibility, and finally, digital preventive measures as modern mechanisms for reducing environmental damage in the digital age.

First: Environmental Compensation

Environmental compensation is considered one of the most important recent developments in the field of civil liability. It is no longer limited to monetary compensation for damages but aims to restore the environment to its state before the damage occurred, whenever possible. This type of compensation is based on the idea of environmental rehabilitation through repairing damaged elements such as soil, water, and air, or replacing them with alternative environmental means. This achieves the restoration of ecological balance rather than simply providing financial compensation. (Salima Amri, Saliha Shatibi, 2023/2024, p. 53.)

Environmental compensation is also characterized by its holistic nature, taking into account not only the interests of the affected individual but also the collective interest and the future of the environment, making it more suitable for the complex nature of environmental damage. This approach reinforces the "polluter pays" principle, which requires the party responsible for the damage to bear the costs of repair and rehabilitation, including the technical and environmental expenses necessary to restore the damaged ecosystem. (Salima Amri, Saliha Shatibi, previous reference, p. 78.)

Therefore, environmental compensation represents a shift from the logic of traditional compensation to that of sustainable environmental redress, combining environmental justice with the preservation of natural resources for present and future generations.

Second: Insurance

Environmental insurance is one of the most important modern mechanisms for ensuring effective compensation for environmental damage. It transfers the burden of financial risks resulting from hazardous activities from the polluter to the insurance company, thus guaranteeing preemptive financial coverage when damage occurs. This system is particularly important given the difficulty in predicting environmental

damage and its wide-ranging impact, as it allows for the immediate provision of financial resources for rehabilitation and damage repair without waiting for the resolution of legal disputes.

Environmental insurance also contributes to enhancing risk prevention, as it encourages economic institutions to adhere to safety standards and reduce pollution. This is because insurance companies require the implementation of preventive measures and risk reduction before granting insurance coverage. Therefore, it not only performs a compensatory function but also a deterrent and regulatory one, contributing to improved environmental behavior among economic actors.

Accordingly, environmental insurance represents a dual tool that combines ensuring rapid and effective compensation on the one hand, and promoting environmental prevention on the other, making it a fundamental element in modern models of sustainable environmental responsibility.

Third: Guarantees

In the field of environmental responsibility, guarantees refer to the set of legal and financial mechanisms through which the entity undertaking a risky activity commits to providing advance coverage for potential environmental damage. This ensures the possibility of effective compensation and redress should damage occur. These guarantees include bank guarantees, mandatory insurance, or the allocation of advance financial credits, which are usually required before licensing industrial or digital activities with a potential environmental impact.

This mechanism is primarily a preventative tool rather than a compensatory one, as it aims to ensure the availability of a readily accessible source of funds to cover the costs of environmental rehabilitation and compensation without delay, especially in cases where identifying the responsible party is difficult or where multiple stakeholders are involved. Guarantees also contribute to strengthening the environmental compliance of economic institutions by linking the practice of activity to the extent of commitment to providing the necessary financial cover to address potential risks. (Youssef Ahmouda, previous reference, p. 117.)

Therefore, the guarantee system represents a significant development in modern compensation models, combining prevention, deterrence, and compensation, and reinforcing the concept of proactive liability for environmental risks within the framework of sustainable development.

Fourth: Digital Preventive Measures

Digital preventive measures are among the most important modern mechanisms for developing sustainable environmental compensation models. They aim to prevent environmental damage before it occurs by employing digital technologies for early detection and risk prediction. These measures include the use of artificial intelligence systems, the Internet of Things, and big data analytics to continuously monitor industrial and digital activities, enabling early detection of any malfunctions that could lead to potential environmental damage. These measures also contribute to enhancing the effectiveness of environmental liability by reducing the need for subsequent compensation, shifting the legal system from a logic of redress after damage has occurred to one of proactive prevention. Early warning systems and digital monitoring are among the most prominent tools of this approach, enabling rapid intervention to correct deviations before their environmental impacts worsen.

Thus, digital preventive measures represent a qualitative leap in environmental risk management, combining technology and law within a framework aimed at protecting the environment and minimizing losses, in line with the principles of sustainable development.

Conclusion

In conclusion, this study demonstrates that civil liability for environmental pollution damage in the digital age is no longer limited to traditional fault-based rules. Instead, it is gradually moving towards adopting

more flexible and effective approaches that align with the nature of contemporary environmental damage. Digital transformation has given rise to new and complex forms of indirect environmental pollution, where technical and environmental elements intertwine, making it more difficult to prove and precisely determine causation.

The research also shows that traditional frameworks, despite their importance, are no longer sufficient on their own to address these challenges. This necessitates the development of modern legal models based on strict liability, expanding the scope of compensation to include environmental reparations, and adopting preventative and digital mechanisms to mitigate damage before it occurs. Furthermore, the importance of emerging tools such as environmental insurance, financial guarantees, and digital preventative measures has become apparent in enhancing the effectiveness of legal protection for the environment. In this context, digital transformation necessitates adapting traditional frameworks for civil liability by adopting hybrid models that combine the provisions of the Algerian Civil Code, Environmental Protection Law No. 03-10, and relevant international instruments. This includes strengthening digital evidence mechanisms and expanding the scope of environmental insurance, thereby addressing invisible and complex damages and ensuring more effective and sustainable environmental redress.

Consequently, the future of civil liability in this area is moving towards building an integrated system that combines prevention, compensation, and digitalization. This system aims to balance the demands of technological development with environmental protection and enshrines the principle of sustainable development as the governing framework for contemporary legal relations.

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