

Smart Adaptation to Climate Change: Reconsidering Its Relationship with the Principles of International Environmental Law and Adaptive Regulation

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Abstract

Adaptation to climate change, as a complementary strategy to the reduction of greenhouse gas emissions, has largely been described in the literature of international environmental law as a soft and indeterminate obligation; an obligation that, in foundational instruments such as the United Nations Framework Convention on Climate Change and even the Paris Agreement, has mostly remained within the framework of conditional and guiding language and lacks a clear legal enforcement mechanism. Adopting a descriptive-analytical approach, this article reconsiders the emerging concept of “smart adaptation” in light of the customary principles of international environmental law—particularly the precautionary principle, the principle of prevention, and the principle of environmental impact assessment—as well as the principles of environmental democracy. The findings of the study indicate that smart adaptation, as distinct from conventional adaptation and in contrast to the concept of maladaptation, is grounded in data-driven decision-making, predictability, principled flexibility, and participatory governance. By relying on a systematic cycle of planning, assessment, implementation, and monitoring, it can partially compensate for the gaps in the soft obligations contained in international instruments such as the Paris Agreement. The experience of the European Union in the document “Forging a Climate-Resilient Europe” (2021), which is structured around the three axes of smarter, more systemic, and faster adaptation, represents an example of the practical realization of this regulatory model. The article concludes that the principle of coordination and integration, the principle of continuous supervision and monitoring, and the principle of principled flexibility constitute the fundamental pillars of smart adaptation regulation, and that their realization, particularly in countries such as Iran, will face structural obstacles in the absence of binding national legal frameworks.

Keywords: smart adaptation, international environmental law, precautionary principle, environmental impact assessment, climate regulation, sustainable development, maladaptation.

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1. Introduction

Climate change, as one of the mega-challenges of the present era, compels national and international legal systems to rethink the fundamental concepts of adaptation. In recent decades, global environmental discourse has largely focused on reducing greenhouse gas emissions; however, with the scientific consolidation of the fact that a significant portion of climate impacts will persist for decades, and even centuries, even if emissions are completely halted, adaptation has been elevated from a secondary issue to a fundamental pillar of climate policymaking (Bodansky et al., 2017). This new status has been reflected in international legal literature, particularly after the adoption of the Paris Agreement and the allocation of an independent article to the global goal on adaptation; although, as will be shown, this reflection has still largely remained at the level of soft obligations.

Nevertheless, the mere adoption of adaptive measures does not, by itself, guarantee the reduction of vulnerability. Experience has shown that uncoordinated measures or measures lacking analytical and institutional support may themselves become sources of new vulnerabilities; a phenomenon known in the scientific literature as “maladaptation” (Crespi, 2000; Magnan et al., 2016). This reality reveals a fundamental gap in the classical theory of adaptation: the label “adaptation” is not in itself protective, and what is decisive is the manner in which adaptive measures are designed, implemented, and continuously evaluated. In response to this risk, the concept of “smart adaptation” has emerged as a fundamental redefinition in the understanding and design of adaptation; an approach that replaces the linear, closed, and top-down view of classical adaptation with a data-driven, learning-oriented, participatory, and flexible approach, placing the element of “sustainability” at its center.

The main question of this article is what relationship smart adaptation has with the fundamental principles of international environmental law and how it can, within the framework of a coherent regulatory system, cover the gaps in the soft obligations of existing international instruments. The guiding hypothesis of this study is that the implementation of smart adaptation strategies, within the framework of established environmental laws and institutions, strengthens policy innovation and ensures adequate monitoring for addressing potential environmental and social risks. The research method is descriptive-analytical and based on the library-based study of international instruments, judicial practice, and the existing scientific literature. Accordingly, the present article is organized into three sections: first, the concepts of maladaptation and smart adaptation are explained in light of the Sustainable Development Goals, with special focus on the two areas of food security and the development of sustainable cities; second, the relationship between this concept and the customary rules of international environmental law—the precautionary principle, the prevention principle, and the principle of environmental impact assessment—as well as the principles of environmental democracy, is examined; and third, the principles and criteria of smart adaptation regulation are analyzed in detail, relying on the practical experience of the European Union in the document “Forging a Climate-Resilient Europe.”

2. Smart Adaptation in Light of Sustainable Development

The image of a city that, through modern technologies, continuously adapts itself to climate change—streets equipped with smart sensors for storing and optimizing rainwater consumption, buildings that supply their energy from renewable sources, and forecasting systems that warn residents of the occurrence of extreme weather events—depicts a future in which adaptation to climate change is not merely a necessity but also an opportunity for sustainable development. With the increasing intensity and frequency of hazards arising from climate change, traditional methods of confronting these challenges are no longer sufficient, and cities and communities require solutions that not only reduce vulnerability but also increase their adaptive capacity and resilience.

2.1. From Maladaptation to Smart Adaptation

The concept of maladaptation was first introduced in the field of evolutionary biology, where traits or behaviors that were once beneficial for the survival and reproduction of organisms lose their effectiveness, and may even become harmful, when environmental conditions change (Crespi, 2000). This concept has also been applied in climate change studies and refers to actions undertaken with the intention of reducing the negative effects of climate change but which, in practice, lead to increased

vulnerability or unintended consequences (Magnan et al., 2016). Adopting a sustainable approach to identifying and avoiding maladaptation is essential for the development of effective adaptation strategies; this requires a deep understanding of environmental, social, and economic dynamics, as well as a careful assessment of the short-term and long-term consequences of adaptive measures.

The construction of large dams for water-resource management without conducting environmental impact assessment is one of the clear examples of maladaptation. An example of this reality in Iran is the Khersan 3 Dam case; a dam that was designed with the apparent purpose of water-resource management and hydropower generation so as to appear to offer a solution for clean energy supply, but in practice, due to its extensive environmental and social consequences, was found to be inconsistent with laws including the Third and Fifth Development Plans. The Eighth Branch of the Court of Appeals of Kohgiluyeh and Boyer-Ahmad Province issued its final ruling prohibiting the construction of this dam in 2025 (Isna, 2025); a ruling that had been preceded by similar concerns regarding the lack of an independent environmental assessment for the project (Borna, 2022). This example shows that any adaptive measure must be designed with precision and comprehensiveness in order to prevent unintended consequences; a reality that establishes a deep connection between adaptation and sustainability, since only strategies that simultaneously reduce vulnerability and promote sustainability can be effective in the long term.

In contrast to maladaptation, “smart adaptation” is proposed as a strategy that can be analyzed at two levels. At the general level, smart adaptation is oriented toward selecting the most sustainable forms of adaptation, those that impose the lowest economic, social, and environmental costs on society. This definition has a justice-oriented and sustainable-development-based approach in which guaranteeing the rights of present and future generations and reducing social gaps are regarded as fundamental principles; in this sense, smart adaptation may be considered synonymous with “sustainable adaptation.” At the specific level, smart adaptation refers to the use of advanced technologies and innovative approaches to improve the resilience of communities and environmental systems against climate change. This level includes the use of tools such as artificial intelligence, the Internet of Things, big-data analytics, and predictive models in order to optimize decision-making and increase the efficiency of adaptation strategies (Kazemalilou & Jamshidi, 2023). One of the prominent examples of smart adaptation at this level is climate-smart agriculture, which, by using sensors for temperature, air and soil humidity, and other influential gases, reduces farmers’ vulnerability to climate change and increases productivity.

2.2. *The Smart Adaptation Cycle*

By drawing on the framework of “climate-smart conservation,” introduced by the National Wildlife Federation of the United States in a study focused on wildlife conservation in the face of climate change (Score et al., 2021; Stein et al., 2014), a dynamic and systematic cycle for smart adaptation can be outlined. This cycle, by emphasizing a flexible process and continuous revision, offers an effective solution for addressing the challenges of climate change and, while corresponding with fundamental principles of international environmental law such as the precautionary principle and the principle of good governance, functions as an operational tool for realizing these principles.

The first step in this process is the determination of the objective and scope of planning, which forms the foundation of all subsequent measures. The precise definition of objectives and the examination of climate and social vulnerabilities, alongside the assessment of institutional and legal capacities, pave the way for effective adaptation. The second stage, the assessment of climate impacts and vulnerabilities, is of great importance in adopting informed decisions based on scientific evidence. Access to reliable and up-to-date information plays a central role in this process, and without it, climate decision-making may lack the necessary effectiveness. The distinguishing feature of smart adaptation is the possibility of revising the scope and measures of adaptation during the process; this is because adaptation is understood as the adjustment of responses to climate change, which may increase or decrease the threshold of vulnerability, and these thresholds may change over time depending on adaptation measures (Bodansky & van Asselt, 2024).

The identification of adaptation options is a turning point in this process, as it involves formulating appropriate options based on previous assessments and revised objectives. These options must be compatible with the ecological and social characteristics of each region and must be implementable within social, economic, and legal contexts. Subsequently, the evaluation and selection of adaptation options, including cost-benefit analysis, are carried out so that the best and most flexible

solutions are selected. After that, the implementation of prioritized adaptation measures is carried out through the provision of financial resources, institutional capacities, and inter-institutional cooperation. The final stage is the monitoring of the effectiveness of measures and ecological responses, which enables the continuous evaluation and correction of measures. At this stage, the effectiveness of measures in reducing climate vulnerabilities and strengthening ecosystem resilience is measured through quantitative and qualitative indicators (De Pinto et al., 2020).

2.3. *Alignment with the Sustainable Development Goals*

The principle of sustainable development in international environmental law, as a concept that establishes a balance between the requirements of economic development and the necessities of environmental protection, first appeared in a coherent and codified form in the Rio Declaration of 1992 (Pourhashemi & Arghand, 2023). In the sphere of international judicial practice, the judgment of the International Court of Justice in the case known as Gabčíkovo-Nagymaros is regarded as a turning point in the consolidation of this principle. This dispute, which arose between Hungary and Slovakia over the construction of a dam and its environmental impacts, led the Court to introduce the concept of sustainable development as a reconciliatory solution that guarantees a balance between the developmental interests of states and environmental requirements (Razavinejad, 2022). The Paris Agreement also treats sustainable development not as a peripheral matter but as a fundamental necessity. In the preamble to this agreement, sustainable development and poverty eradication are mentioned as overarching goals in connection with climate action, and Article 7 of this international instrument also emphasizes the need to increase adaptive capacities, strengthen resilience, and reduce vulnerability to climate change, with a clear objective: to ensure development that preserves not only the needs of the present generation but also the rights of future generations in the use of resources (Bodansky, 2016).

2.3.1. *Food Security*

In 2010, at The Hague Conference on Agriculture, Food Security and Climate Change, the new concept of “climate-smart agriculture” was introduced. At this meeting, it was warned that if current approaches in agricultural planning and policymaking did not change, this sector would not only face increased financial and human risks but would also become a system incapable of ensuring food security. Climate-smart agriculture is an innovative approach that helps farmers adapt to climatic changes while also increasing their productivity and income. This approach pursues three key objectives: sustainably increasing agricultural productivity, strengthening resilience to climate change, and reducing greenhouse gas emissions (Lipper et al., 2017). In order for food security not to be endangered and for development to continue sustainably, accurate and real-time weather data on a large scale are required. These data must be analyzed so that the complex patterns developed in the form of big data can be correctly understood and predicted. In this regard, big-data tools play a key role in helping farmers and policymakers make better decisions (De Pinto et al., 2020).

The use of modern technologies for ensuring food security requires careful assessment of their environmental impacts and efficiency. Although smart agricultural systems, such as automated irrigation based on Internet of Things sensors, can be effective in optimizing resource consumption, evidence shows that improper implementation of these technologies may have reverse effects. For example, the recycling of electronic products related to these systems requires a specific method in order to prevent increased environmental risks (Khosravi, 2023). Therefore, for the sustainable use of technology in food security, planning and implementation processes must be evaluated on the basis of a comprehensive framework that considers not only economic benefits but also environmental consequences and long-term sustainability. By creating a balance among environmental protection, social justice, and economic growth, this approach plays a particularly key role in realizing the second Sustainable Development Goal (SDG 2), which concerns ending hunger, achieving food security, improving nutrition, and promoting sustainable agriculture.

2.3.2. *Development of Sustainable Cities*

The eleventh Sustainable Development Goal (SDG 11), which emphasizes the creation of sustainable, resilient, and inclusive cities and communities, was formulated in response to the growing challenges of urbanization and climate change. Modern

cities, especially metropolises, are highly vulnerable to climate change due to high population density and the concentration of critical infrastructure. Phenomena such as heatwaves, flash floods, and severe environmental pollution not only reduce citizens' quality of life but also place additional pressure on urban resources. In this context, smart adaptation has emerged as a new solution that increases urban resilience against climate challenges through the use of advanced technologies. In particular, smart cities use tools such as the Internet of Things, big data, and artificial intelligence for continuous monitoring of environmental conditions and optimal resource management. Advanced flood-management systems that determine optimal drainage routes through the analysis of real-time data are an example of this application, which can prevent extensive damage during heavy rainfall (Fuldauer et al., 2022).

Studies conducted in cities such as Rotterdam and Antwerp show that integrating smart technologies into urban planning has led to improved urban resilience and sustainability (Mees & Driessen, 2011). In the same vein, analysis of the positioning of climate adaptation within the context of the European smart city shows that the model of the "sustainable smart city," through the use of technological infrastructure, a data-driven approach, and citizen participation, can play an effective role in strengthening urban resilience. From this perspective, the connection between technology and nature will be effective when adaptation policies, on the one hand, acquire an ecological substance and, on the other hand, are integrated with new forms of participatory governance (Fernández & Peek, 2020). Therefore, smart adaptation can be used as an effective tool for the development of sustainable cities resistant to climate change, provided that the integration of advanced technologies with smart policymaking takes place within a transparent and accountable legal framework.

Despite the key role of smart technologies in enhancing urban resilience, the widespread use of these technologies in adaptation to climate change itself poses challenges for sustainable development. One of the most important of these challenges is increased energy consumption and, consequently, increased carbon emissions resulting from digital infrastructure. Data centers, big-data processing networks, and artificial-intelligence systems that support the functioning of smart cities depend on high energy consumption. Another challenge is the increase in the volume of electronic waste generated by the rapid growth of smart technologies. Digital equipment, environmental sensors, and communication infrastructure often have limited life cycles, and their constant replacement leads to the accumulation of electronic waste, the recycling of which is costly and complex due to the presence of heavy metals and toxic materials (Khosravi, 2023). These two challenges show that, without comprehensive assessment of environmental consequences, the use of technology in smart adaptation may, instead of reducing climate vulnerability, itself become a factor that intensifies environmental crises. Therefore, it is necessary to adopt a systematic approach that considers pre-implementation and post-implementation assessment of measures within a cyclical and dynamic framework.

3. The Relationship between Smart Adaptation and the Principles of International Environmental Law

In the dynamic field of international environmental law, what appears more necessary than ever is a reconsideration of the relationship between emerging concepts and the traditional principles of this legal system. Is a concept such as smart adaptation—which, on the surface, is based on modern technologies, data processing, and prediction-based policymaking—merely a managerial response to climate complexities, or, as some emphasize, does it possess a value-based, institutional, and even normative dimension that directly connects it to the foundations of international environmental law? This question becomes particularly important when we recall that the principles of international law have largely emerged from gradual developments and have been constructed through state-centered practices and classical treaties, whereas smart adaptation arises from a reality that is more dynamic, more complex, and at times more non-state-oriented than before. The examination of this relationship is conducted along two axes: customary rules and the principles of environmental democracy.

3.1. Relationship with the Customary Rules of International Environmental Law

Customary rules in international environmental law play an irreplaceable and problem-solving role in circumstances where treaties are sometimes accompanied by delay, caution, or limitations in scope and membership. Custom in this field is not merely a reflection of the repetition of state conduct; rather, it is a normative and driving structure that arises from collective and systematic responses to environmental risks. The distinguishing feature of custom in environmental law lies in the speed

of its formation and its flexibility in responding to crises and emerging necessities. Unlike other areas of international law, where the process of customary formation may take years, here custom functions as an immediate response to existing gaps (Mayer, 2021).

3.1.1. *The Precautionary and Prevention Principles*

In international environmental law, the two fundamental principles of prevention and precaution play a crucial role in guiding the actions of states. The prevention principle, which is rooted in the long-standing tradition of international law, requires states to prevent environmental harm to other countries. The arbitral award in the Trail Smelter case of 1941 between the United States and Canada is a clear example of the confirmation of this principle, emphasizing the prohibition of harmful use of territorial sovereignty. By contrast, the precautionary principle, arising from modern concerns about climate change and emerging forms of pollution, is a response to scientific uncertainty in environmental matters. This principle was first raised in soft-law instruments such as the 1984 Bremen Ministerial Declaration on the Protection of the North Sea and the 1987 Montreal Protocol, and was then widely accepted in Principle 15 of the 1992 Rio Declaration as a strategic rule for managing environmental challenges (Pourhashemi & Arghand, 2023).

Despite their conceptual overlap, the prevention principle and the precautionary principle have fundamental differences in terms of scientific foundations, the time of application, and the nature of legal binding force. The prevention principle is based on the existence of sufficient scientific evidence of environmental harm and is applied when the risks arising from an activity have been clearly established. By contrast, the precautionary principle requires preventive measures even under conditions of scientific uncertainty in order to avoid possible environmental damage. In terms of legal status, the prevention principle has been accepted as a customary rule in the international system, as the International Court of Justice emphasized its binding character in the Gabčíkovo-Nagymaros case (Razavinejad, 2022); however, the precautionary principle is still in the process of customary formation and has mostly been introduced in international instruments such as the Framework Convention and the Paris Agreement as an operational strategy rather than as a binding obligation (Molaei et al., 2019; Razavinejad, 2022). These differences have important legal consequences for state obligations and international practice. Nevertheless, these two principles, alongside one another, strengthen the structure of international environmental law and guide states, as two complementary pillars, toward environmental protection.

Smart adaptation, as an emerging concept, embodies the precautionary and prevention principles in a modern and effective form. By relying on advanced technologies, data-driven approaches, and flexible management, this approach enables states to confront environmental crises before they reach critical thresholds. In this regard, the smart approach to climate change adaptation gains additional importance as an instrument that can assist states in fulfilling prevention. The use of artificial-intelligence models to predict climate change, the development of early-warning systems, and the use of environmental monitoring technologies are clear examples of the link between this principle and modern adaptation solutions. On the other hand, given that climate change has a complex and unpredictable nature (Selje et al., 2024), one cannot wait for scientific certainty and then act; rather, possible scenarios must be assessed through risk-analysis tools, and policies must be formulated on the basis of precautionary considerations. The synergy of these two principles with smart adaptation will lay the groundwork for sustainable development and effective environmental protection, because the dynamic nature of climate challenges requires movement toward new and flexible approaches that can combine both scientific requirements and legal obligations within a dynamic and operational framework.

3.1.2. *The Principle of Environmental Impact Assessment*

Among the key principles of international environmental law for the realization of good governance, the principle of environmental impact assessment (EIA) has a distinguished status. This principle plays a decisive role in guiding states toward informed decision-making consistent with the requirements of sustainable development. It requires states, before implementing projects that may have adverse effects on the environment, to examine their possible impacts and adopt appropriate measures to reduce negative consequences. For conceptual distinction, this principle, unlike general environmental assessment (EA),

which has a broader scope and includes the general examination of the environmental status of a region, has a narrower scope and evaluates the effects of a specific project or activity on the environment.

Within the framework of the gradual evolution of international environmental law, the principle of environmental impact assessment has acquired a unique position and, through judicial practice, particularly the judgments of the International Court of Justice, has gained a customary and general character. Through its important judgments in the Gabčíkovo-Nagymaros case of 1997, the Pulp Mills case of 2010, and finally the Construction of a Road in Costa Rica along the San Juan River case of 2015, the Court gradually and step by step paved the way for recognizing this obligation as part of general international law (Ziaei & Rashidi, 2021). What can be inferred from this trajectory is the gradual acceptance of environmental assessment not merely as an ethical requirement or contractual obligation, but as a binding custom that states are required to observe, except in cases of repeated and reasoned initial objection. This independence does not mean separation from general principles; rather, it indicates the elevation of its status within the hierarchy of sources of international law, such that today, in judicial practice, this principle is considered a necessary precondition for realizing sustainable development and ensuring the environmental obligations of states.

Smart adaptation, as one of the evolved manifestations of adaptation to climate change, is not merely a technical approach to environmental risks; rather, its institutional and normative formulation is based on a form of legal rationality grounded in foresight. In this regard, the principle of environmental impact assessment, as one of the fundamental origins of prevention in international environmental law, assumes a central position in the realization of smart adaptation. The conjunction of this principle with smart adaptation is properly understood when environmental impact assessment is viewed not merely as an instrument for measuring the consequences of a single project, but as an analytical and driving infrastructure for climate policymaking (Raei Dehghi et al., 2023). Within such a framework, the results of continuous, dynamic, and data-driven assessments will play a role not only in identifying vulnerable points, but also in designing and revising adaptation measures appropriate to climate variability. This is especially so because the rationality governing smart adaptation requires decision-making processes to move beyond static and episodic forms and to become mechanisms that are constantly updated and based on environmental feedback. From this perspective, smart adaptation may be regarded as the concrete manifestation and conceptual extension of the principle of environmental impact assessment in the sphere of climate policymaking; a manifestation that, by elevating this principle beyond mere executive obligations, places it at the center of anticipatory environmental governance.

3.2. *Relationship with the Principles of Environmental Democracy*

Climate change is not merely a threat to the environment, but also a factor that intensifies ecological and social injustices, because the groups and countries that have played the smallest role in producing greenhouse gases bear the greatest negative effects. This inequality in vulnerability requires a response from international law that simultaneously emphasizes the components of climate justice and procedural justice. In this regard, adaptation to climate change must be designed in such a way that it is not only effective from a technical and environmental perspective but also contributes to strengthening the democratic foundations of decision-making and compensating for justice-oriented gaps.

3.2.1. *Access to Environmental Information*

Free access to information is the foundation of public participation in environmental decision-making. Without awareness of the challenges, policies, and solutions related to climate change, public participation will remain merely symbolic. In the system of international environmental law, particularly within the framework of the Aarhus Convention, the role of states in environmental information provision is not limited to passive responsiveness; rather, an affirmative and structural responsibility for active information provision has also been placed upon them. Accordingly, states are required to adopt a transparent procedure and provide environmental information to the public in a systematic, up-to-date, and understandable manner, without the need for citizens to submit a request (Ramezani et al., 2016).

This fundamental distinction between active information provision and passive information provision reflects a shift in perspective from the exclusive and authoritarian approach of states toward participatory and accountable governance in the

environmental field. This approach enhances transparency, increases public trust, and strengthens mechanisms of popular oversight. The Aarhus Convention Compliance Committee, in its practice, including in the case brought against the Government of Belgium, treated lack of access to environmental information as a violation of citizens' fundamental rights (Ramezani et al., 2016). This practice shows that the right to environmental information has consolidated its place not only in international instruments but also in judicial practice.

Smart adaptation to climate change requires decision-making based on accurate, transparent, and up-to-date data; data to which active and systematic access plays a decisive role at all stages of the smart adaptation cycle. In this regard, the right of access to environmental information is not only regarded as one of the fundamental rights of citizens, but also as a vital instrument for effective decision-making by policymakers, economic actors, and civil institutions in reducing the negative impacts of climate change. The experience of the World Summit on the Information Society (WSIS) in Geneva and Tunis in 2003 and 2005, and the Geneva Declaration of Principles that resulted from it, show that the effective use of information and communication technologies has been regarded as a vital instrument for achieving sustainable development (Kadkhodai Eliadrani, 2024). Through this path, smart cities can be achieved that, relying on data, optimize their resources and provide effective infrastructure for improving citizens' lives.

3.2.2. *Public Participation*

The principle of public participation in international environmental law is recognized as one of the fundamental foundations of good environmental governance. The Rio Declaration of 1992, in Principle 10, emphasizes the necessity of public access to environmental information, active participation in environmental decision-making, and the right of access to environmental justice (Pourhashemi & Arghand, 2023). This declaration treats participation not only as a right but also as a key instrument for achieving sustainable development. With the development of this perspective, the Aarhus Convention of 1998, as a turning point, formulated state obligations in a more binding manner and recognized people's rights in three key dimensions: access to information, participation in decision-making, and access to environmental justice.

The realization of public participation in the field of climate change adaptation requires changes in collective and individual beliefs and values concerning the environment and related responsibilities. The traditional approach, which viewed adaptation merely as a technical and bureaucratic solution, no longer responds to the complexities of the climate crisis. People will participate actively in adaptation processes when they are not only aware of the risks and consequences of climate change, but also feel ownership and responsibility in decisions related to adaptation policies. Smart adaptation will possess full legitimacy only if this participation is institutionalized at all stages of the adaptation cycle—from priority-setting to monitoring outcomes—and if vulnerable groups, including residents of marginalized areas, Indigenous peoples, and future generations, are able to participate in determining their own climate future. The experience of various countries has shown that successful adaptation programs are those that rely on the capacities of local communities, social networks, and civil institutions. Therefore, the transition to an approach based on public participation requires changes in governance systems and acceptance of the reality that smart adaptation is not merely a governmental responsibility, but a collective obligation that must be realized through the cooperation of all stakeholders (Fuldauer et al., 2022).

4. **Regulation of Smart Adaptation: Principles and Practical Experience**

Climate change, as a global and complex phenomenon, has created an unprecedented challenge to traditional models of governance and regulation; a challenge characterized by broad uncertainty, the nonlinearity of developments, the multilevel and cross-sectoral nature of impacts, and the risk of crossing environmental thresholds. Under such conditions, reliance on classical methods of legislation—based on relative predictability, long-term stability, and reactive responses—no longer appears effective (Craig, 2010). Indeed, rules and policies designed on the assumption of environmental stability or gradual change lose their effectiveness in the face of the dynamism and increasing speed of climate developments, and may increase vulnerability rather than reduce it (Yeganeh et al., 2023). This situation raises a fundamental question: how can legal and institutional systems be rearranged in such a way that they are not only resilient to rapid climate changes, but also capable of responding to changing conditions with flexibility, dynamism, and timely predictability?

4.1. *Fundamental Principles of Smart Adaptation Regulation*

In the era of climate change, whose defining feature is the environmental, economic, and social interconnectedness of phenomena from the global to the local scale, thinking about adaptation without considering the principle of coordination and integration in regulation is not only ineffective but sometimes contrary to the fundamental objectives of climate policy. Smart adaptation, as a multidimensional strategy, requires that policies, institutions, and legal instruments be formed in effective and continuous interaction with one another; because the absence of coherence among governance levels, sectoral fields, and different stakeholders can itself become a factor that deepens the vulnerability of social-ecological systems. Traditional regulation, which often relied on linear and sectoral models, lacks the capacity to respond to the complex and fluid challenges of climate change. Only through horizontal coordination among areas such as agriculture, energy, water, and health, as well as vertical coordination among local, national, and international levels, can one move toward adaptive and smart governance (Yeganeh et al., 2023). The practical realization of this principle requires the design and application of a set of institutional and legal mechanisms capable of effectively and sustainably connecting different sectors, levels, and stakeholders. The creation of intersectoral coordinating institutions responsible for linking various sectors such as the environment, energy, agriculture, and health is of great importance. These institutions, by integrating climate policies, mainstream climate impacts into all areas of decision-making and realize the principle of “internalizing climate considerations.” The principle of coordination provides not only a basis for institutional coherence but also a framework for the logical connection among other principles of smart adaptation, such as continuous monitoring and principled flexibility. In other words, without coordination at all stages of the adaptation cycle, mechanisms of monitoring and revision, and even adaptive adaptation itself, will become fragmented and inconsistent and will ultimately weaken the effectiveness of climate regulation.

Yeganeh, Mohaghegh, Najla, and Famil Saeidiyan, in explaining the framework of agile regulation, emphasize the necessity of connecting the principles of coordination, monitoring, and flexibility in the design of dynamic regulatory systems (Yeganeh et al., 2023). This approach is fully aligned with the inherent characteristics of smart adaptation and shows that these three principles, in practice, do not operate independently but as an interconnected system in which the absence of any one of them will weaken the function of the other two.

4.2. *Practical Experience: The Document “Forging a Climate-Resilient Europe”*

The European Union, by adopting the European Climate Law in 2021, set climate adaptation objectives in Article 5 of that law (Bodansky & van Asselt, 2024). In accordance with the objectives of the Paris Agreement, Member States must ensure continuous progress in increasing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change. To achieve these objectives, the law sets out a series of operational duties for the European Commission and Member States, including the formulation of adaptation strategies, assessment of climate adaptation progress at the national and Union levels, broad public participation, and the creation of a scientific advisory body at the European level. Article 5(2) of this law requires the European Commission to adopt a European Union-level strategy for adaptation to climate change in line with the Paris Agreement and to review it every five years. In February 2021, the European Commission adopted the new climate change adaptation strategy, which builds on the first EU strategy from 2013. Whereas the 2013 strategy focused more on knowledge creation, the 2021 strategy focuses on the development of solutions from planning to implementation of adaptation measures (Bodansky & van Asselt, 2024). The overall objective of this new strategy is to achieve a climate-resilient society in Europe by 2050, based on three axes.

4.2.1. *Smarter Adaptation*

In the document “Forging a Climate-Resilient Europe,” the European Commission presents the concept of “smarter adaptation” as a fundamental pillar that emphasizes the need to improve data quality, the predictability of climate developments, and knowledge-based decision-making. In order to achieve this objective, the European Commission identifies continuous monitoring of ecological and social indicators as one of the requirements of smarter adaptation. The first step of the European Union in this regard is the commitment to expanding the frontiers of climate knowledge through improving data, enhancing

damage modeling, and analyzing the connections between climate change and social vulnerabilities; a matter that is directly related to the principle of continuous monitoring in smart adaptation regulation (Bodansky & van Asselt, 2024).

The second fundamental pillar in strengthening smarter adaptation is the improvement of data systems related to climate risks and losses, including the creation of comprehensive databases such as the Climate Risk Data Hub, which has been placed on the agenda. This initiative is fully consistent with the principle of continuous monitoring and the obligation of periodic vulnerability assessment. This is because, in the smart adaptation cycle, the availability of reliable data on past and current risks and losses is a prerequisite for designing informed and forward-looking adaptive responses. In order to deepen the data-driven foundations of smart adaptation, the European Commission emphasizes strengthening integrated climate knowledge systems, particularly enhancing the role of Climate-ADAPT as an authoritative source of adaptation information. This system is designed to aggregate data, case studies, vulnerability assessment tools, and policy guidelines on a single platform in order to facilitate institutional learning and evidence-based decision-making. In addition, the Destination Earth project, designed to create a highly accurate digital model of the Earth system for simulating climate scenarios, may be considered a leap toward improving the predictability of developments and strengthening data-driven adaptation (Yeganeh et al., 2023).

4.2.2. *Systemic Adaptation*

In confronting the complex and interconnected realities of climate change, the need to find an approach capable of managing the various dimensions of climate risks synergistically has become increasingly prominent. Systemic adaptation is a response to this necessity; an approach that emphasizes the integration of climate considerations into all levels and areas of governance and seeks to prevent the fragmentation and inconsistency of sectoral policies. Within this framework, adaptation is no longer regarded as a detached and episodic measure against specific risks, but as an inseparable part of developmental, economic, social, and environmental planning. One of the prominent examples of the European Union's efforts to realize systemic adaptation is its support for improving the quality of national and local adaptation strategies and plans. In this regard, the development of coherent reporting frameworks, the provision of technical support, and the creation of climate-resilience indicators have been introduced as key tools for measuring and assessing adaptation progress (Bodansky & van Asselt, 2024).

In addition to improving national and supranational adaptation plans, the European Commission places special emphasis on the need to develop resilience at local levels and strengthen climate justice. This approach is based on the reality that the effects of climate change disproportionately affect local communities, particularly vulnerable groups, while adaptive and response capacity at the local level is a determining factor in the success of adaptation strategies. In addition, the European Union has introduced the principle of "coherent policies" as an essential precondition for the success of adaptation measures. On this basis, climate decisions should not be made in a vacuum, but must be actively internalized into macro-level policymaking such as economic development, agriculture, water resources, energy, transport, and health. This approach corresponds precisely with the principle of coordination and integration analyzed in this article.

4.2.3. *Faster Adaptation*

Faster adaptation is a response to the reality that climate phenomena such as severe heatwaves, flash floods, or ecological collapses can occur within short time frames and without prior warning, and that any delay will result in the loss of vital opportunities for effective response. In this regard, the document "Forging a Climate-Resilient Europe" introduces faster adaptation as one of the three fundamental axes of its adaptive strategy and emphasizes the creation of capacities for accelerated decision-making and action in response to emerging climate threats. The European Commission emphasizes the need for institutional preparedness to confront crisis-generating scenarios; scenarios that may manifest themselves in the form of extreme weather events, sudden failures in critical infrastructure, or severe disruptions in food security and water resources (Bodansky & van Asselt, 2024).

A major part of the European Union's strategy for accelerating adaptation processes involves using the capacities of modern digital technologies. Strengthening remote-sensing systems, the Internet of Things, and big-data analytics plays an essential role in accelerating the identification of environmental changes, risk analysis, and the updating of adaptation plans. This orientation corresponds well with the specific definition of smart adaptation, where emphasis was placed on integrating modern

technologies to feed adaptive decision-making and improve the efficiency of continuous monitoring. However, accelerating adaptation processes without careful legal, social, and institutional considerations entails significant risks. The first challenge is the risk of hasty decisions based on incomplete data, which may lead to ineffective policies or even policies that intensify vulnerabilities (Yeganeh et al., 2023). Moreover, accelerating processes may limit the opportunities necessary for effective participation by stakeholders, especially local and vulnerable groups, thereby weakening the principles of environmental democracy and climate justice. Therefore, accelerated adaptation can lead to real resilience against climate change only when it is designed within a dynamic, reviewable cycle based on reliable data; a cycle in which institutional learning, principled flexibility, and meaningful social participation occupy a central position.

5. Conclusion

This article showed that smart adaptation, beyond a merely technical or managerial measure, can be analyzed within the framework of international environmental law as a normative mechanism. This concept, in contrast to maladaptation and in alignment with the principles of sustainable development—particularly in the two areas of food security and the development of sustainable cities—can fill the existing gaps in traditional legal systems of adaptation by relying on data-driven decision-making, predictability, flexibility, and participatory governance. The examination of the relationship between smart adaptation and customary rules—the precautionary principle, the prevention principle, and the principle of environmental impact assessment—as well as the principles of environmental democracy—access to information and public participation—showed that this concept is not only aligned with these fundamental principles, but also acquires a new functional meaning in light of them and is elevated from a merely technological instrument to a mechanism for consolidating anticipatory environmental governance.

The analysis of the European Union’s experience in the document “Forging a Climate-Resilient Europe” confirmed that effective regulation of smart adaptation rests on three pillars: the principle of coordination and integration, the principle of continuous supervision and monitoring, and the principle of principled flexibility. These pillars make policy innovation and more effective monitoring of the social and environmental consequences of climate measures possible. The examination of the three axes of smarter, systemic, and faster adaptation in this document showed that each of these axes is the practical manifestation of one of the three regulatory principles; a matter that confirms the research hypothesis concerning the strengthening of innovation and the assurance of adequate monitoring in light of smart adaptation.

At the same time, the realization of this model without binding national legal frameworks—which remain absent in many developing countries, including Iran—will face serious structural obstacles. The absence of a binding national adaptation plan in higher-level development instruments, and the lack of specific laws supporting climate-vulnerable groups, are among the most important current challenges. These challenges not only increase vulnerability, but also create a rupture between the domestic legal system and the normative developments of the international community in this field. Therefore, institutionalizing smart adaptation in national legal systems requires the formulation of binding plans, the guarantee of continuous monitoring of climate data and public access to them, and the design of institutional accountability mechanisms. Such a measure can establish a firm link between the theoretical foundations of environmental law and the practical necessities of climate-crisis management, and can provide a model for realizing effective climate governance at the national level.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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Conflict of Interest

The authors report no conflict of interest.

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