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Review

Addressing global environmental pollution using environmental control techniques: a focus on environmental policy and preventive environmental management

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Abstract
Global environmental pollution presents formidable obstacles to the long-term viability of the planet. This study synthesized current relevant literature with statistical snapshots from pollution statistics and reports and presented feasible recommendations to address the ramifications of global environmental pollution. A central focus is laid on the importance of preventive environmental management (PEM) and the strategic enforcement of environmental policies (EP), with a detailed exploration of history evolution and current application challenges. Specifically, the study centers on the significance of environmental policy and preventive environmental management in combatting global pollution. The examination encompasses an overview of environmental pollution and its implications for the environment and human health. It explores the role of environmental policy in mitigating environmental pollution, scrutinizes the principles underlying preventive environmental management, and evaluates the effectiveness of environmental management systems in curbing pollution. Furthermore, the study identifies and analyzes the challenges of implementing environmental control techniques, offering recommendations to overcome these obstacles. The outcomes of this research contribute to a more comprehensive understanding of the potential of environmental control methods in tackling global environmental pollution. The study underscores the crucial nature of robust environmental policies and proactive approaches to prevent pollution and foster sustainable development. Additionally, it offers insights into the necessity for collaboration and cooperation among stakeholders at various levels to attain effective pollution control and environmental management.

Keywords Environmental · Pollution · Policy · Emission · Management · Sustainable development · Global

1 Introduction

The environment is essential for sustaining life on earth but the rising global contamination and pollution of the environment has become a significant concern in recent years [1, 2]. Pollution in the environment can occur in different forms including air pollution, water pollution, soil pollution, and noise pollution [3]. Industries can reduce pollution

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by using cleaner production technologies and practices, governments can also enforce regulations and penalties for industries that violate pollution standards [4]. Transportation can be improved by promoting the use of public transport, electric vehicles, and bicycles. Governments can also enforce regulations on vehicle emissions. implementation of proper waste disposal systems to help waste management practices such as recycling and composting [5].

Recognizing that preventing certain pollutions before they occur is not only easier but also essential, a preventive environmental management (PEM) approach becomes paramount. Environmental policy (EP) has a very rich history which has been explored and reported by several studies such as [6–9] and [10], however, EP has not been adequately utilized in addressing pollution globally as several nations over the world have paid little or no attention to environmental policy with several constraints on its implementation. In 2022, [11] reconsidered the strategies employed in the allocation of policies using the computable general equilibrium (CGE) model to conduct a review of instruments of environmental policy, this facilitated the expansion of policies and better criteria for selecting and formulating instruments of EP using practical approaches, Cohen [12] studied the enforcement, monitoring, and compliance to environmental policies. Wu and Zhang [13] studied the strict implementation of EP which led to the remarkable green growth in China and revealed a substantial increase in requirements and innovations of environmental technology as a result of strict implementation of environmental policies.

Environmental contamination and pollution occur when harmful substances and contaminants are released into the air, soil, and water causing significant damage to the environment and human health [14]. A study by Li, Jin [15] showed that air pollution has become a global problem and must be addressed, severe pollution of the ozone has also been reported in China, as a result, China is now considered a hot spot for ozone pollution globally [16]. Environmental contamination and pollution can occur naturally such as wildfires and volcanic eruptions but are largely caused by anthropogenic activities including industrialization, transportation, and agriculture [1]. This pollution can have severe consequences on human health causing a range of health issues including respiratory problems, cancer, and other chronic diseases [17]. chemical contaminants have become major pollutants contributing to a rise in toxicity of the aquatic ecosystem, soil and air [18]. Environmental pollution and contamination can have significant economic consequences including the cost of cleaning up contaminated sites and mitigating the adverse effects on human health [19].

Addressing global pollution involves transforming industrial processes into environmentally friendly and less polluting systems. This can be achieved by identifying potential sources of pollution and implementing preventive measures to minimize environmental impact. One key strategy is adopting cleaner production methods, reducing the use of hazardous chemicals, and minimizing waste generation in industries. Adopting these pollution prevention techniques focuses on eliminating and reducing pollution in industries [20]. Establishing environmental management systems, such as ISO 14001, fosters a culture of continuous improvement and ensures industrial compliance with environmental standards [21]. These measures collectively contribute to creating more sustainable and environmentally responsible industrial processes, fostering a healthier planet for future generations.

Various creative methods are used to track and assess the impact of environmental regulations on pollution management in different nations and regions. Satellite imaging and remote sensing technologies to monitor pollution levels from space. This approach provides a broader perspective, enabling tracking of large-scale environmental changes and assessing the effectiveness of regulatory measures. Foster collaborative international research networks that bring together scientists, policymakers, and experts from various nations [22]. Sharing methodologies, data, and best practices enhances the collective understanding of the global impact of environmental regulations on pollution [23]. Establish global environmental indices that integrate pollution data, regulatory frameworks, and environmental performance indicators. These indices can offer a comparative assessment of nations and regions, encouraging healthy competition and driving continuous improvement in pollution management efforts. Also, collaborative approaches and multilateral environmental agreements can be established, allowing nations to work together towards common goals while still maintaining their autonomy, by allowing nations to set their own environmental goals based on their unique circumstances [24]. This can facilitate the sharing of resources, knowledge, and best practices for pollution management. Additionally, coordinating global environmental policies through platforms like the United Nations can help ensure that the interests and concerns of all nations are taken into account [25]. Institutional quality has a great impact on global environmental pollution control, strengthening institutions can contribute to mitigating environmental effects, with a focus on formulating recommendations applicable [26].

In a world grappling with myriad environmental challenges, there exists a pressing need to address critical gaps on a global scale to reduce and control environmental pollution effectively. As the consequences of climate change intensify, the importance of environmental policies and proactive preventive management strategies cannot be overstated [27].

Revealed the possible detrimental effects of natural resource rent and urbanization on environmental indicators, these factors have a collective impact on carbon emissions, ecological footprint, and carbon footprint. A similar study [28] showed that population density influences CO2 emissions [29]. Confirmed a possible adverse effect of economic growth and biocapacity on the ecological footprint of nations. One of the major barriers to addressing global pollution is the issue of respect for national sovereignty. A study [30] revealed the difficulty of balancing respecting national autonomy and achieving effective global environmental governance. These gaps highlight the need for a review to provide information on the current state of environmental pollution and analysis to improve the understanding and implementation of environmental pollution management strategies on a global scale. Figure 1 illustrates a planet divided by its actions and outcomes. One half is engulfed by the dark smog of industrialization, depicting polluted landscapes, factories belching smoke, and waste-filled waters. The contrasting half radiates with the vibrancy of renewable energy sources, green cities, and clear skies. Central to the image are environmental policies and management tools, symbolizing the transformative journey from pollution to sustainability. This stark dichotomy serves as a visual representation of the crossroads at which global environmental pollution stands and the positive impact that environmental control techniques and policies can have on the world's future and hence the need for this review. Global Environmental pollution cannot be eradicated without understanding the forces and laws that drive pollution in the environment. This review explored and evaluated the existing techniques in EP, PEM and EMS, the gaps, and the need for a holistic approach to addressing global pollution.

Fig. 1 From pollution to preservation: envisioning a cleaner future

2 Preventive environmental management

The concept of PEM uses strategies such as waste reduction, pollution prevention, and resource conservation to identify and prevent potential risks to the environment [31]. PEM is a cost reduction tool which assists organizations in reducing risks to liability through compliance [32], it is implemented through strategies such as environmental management, life cycle assessment (LCA), environmental performance indicators, green procurement, environmental risk assessment and environmental monitoring systems [33]. The initiative of zero manufacturing waste to landfills by Procter and Gamble's aimed at eradicating waste from manufacturing processes and the ecomagination program by General Electric which focused on the development of products and services which are environmentally friendly are all typical practices of PEM [34]. A study by Kazancoglu [35] assessed the effectiveness of PEM strategies and found that for manufacturing companies, there was a reduction in the use of water, energy and waste generation. Another study [36] on prevention of pollution showed a reduction in the use of toxic chemical by chemical manufacturing companies through the use of PEM.

2.1 Environmental management

Environmental management (EM) refers to the practice of managing natural resources, ecosystems, and pollution to ensure their sustainable use and protection, this is achieved through planning, implementing, and monitoring strategies that reduce the negative impact of human activities on the environment [37]. Despite the challenges, EM offers significant benefits such as economic benefits through reduction in costs associated with pollution control [38], improved resource efficiency, and increased market opportunities for sustainable products, social benefits through improved health and quality of life, and enhanced community resilience, regulatory compliance by ensuring organizations comply with environmental regulations and avoid fines and other legal penalties [39]. Some of the strategies employed in EM include; Environmental Impact Assessment (EIA, sustainable resource management, pollution prevention through the implementation of measures to prevent pollution from occurring, including the use of cleaner production technologies and waste minimization practices [40], and environmental management systems, a framework for managing environmental responsibilities and promoting continuous improvement in environmental performance [41].

2.1.1 Principles of environmental management

The major principles in environmental management include sustainability, prevention, precaution and participation. Environmental management ensures that natural resources are used in a way that meets present needs without compromising the ability of future generations to meet their own needs [42], also it emphasizes the need to prevent pollution and environmental damage before it occurs, rather than relying on remediation, it advocates for the precautionary approach, which means taking action to prevent potential environmental harm, even in the absence of scientific certainty and further involves the participation of all stakeholders, including government agencies, industries, communities, and individuals [43]. Some of the challenges in the implementation of environmental management include a lack of data, limited resources, and conflicting priorities [44].

2.2 Environmental management systems (EMS)

Environmental Management System (EMS) is a structured and systematic approach to managing environmental issues and impacts within an organization to achieve sustainable development [45]. EMS focuses on identifying and managing the environmental aspects of an organization's activities, products, and services. It helps organizations to establish and maintain a sustainable approach to managing their environmental impact, comply with environmental regulations, and reduce costs associated with environmental risks [46]. Regulatory bodies conduct regular inspections and audits to ensure that organizations are complying with environmental regulations and EMS standards. The enforcement of EMS standards by regulatory bodies has a significant impact on the environment by ensuring that organizations are managing their environmental impact effectively [47]. The implementation of EMS can result in cost savings through reduced energy consumption, waste reduction, and improved operational efficiency. EMS also helps organizations to demonstrate their commitment to environmental sustainability, which can enhance their reputation and provide a competitive advantage [48]. The implementation of EMS involves several steps, including policy development, planning, implementation, monitoring, and evaluation [49].

2.3 Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a systematic approach employed to assess the environmental consequences of a product, process, or service from its initial extraction of raw materials to its ultimate disposal. LCA takes into account the environmental implications at every stage of a product's life, encompassing raw material extraction, manufacturing, distribution, utilization, and end-of-life management [50]. It offers a comprehensive perspective on the environmental impact of products and processes, empowering companies and policymakers to make sustainable decisions and minimize their ecological burden. Insights should therefore be derived from LCA for eco-labeling, environmental product declarations, and shaping environmental policies and regulations [51]. The typical steps involved in conducting an LCA include goal definition and scope, life cycle inventory, life cycle impact assessment, interpretation and improvement, and decision-making [52, 53].

2.4 Environmental risk assessment

Environmental Risk Assessment (ERA) is a structured process utilized to assess the potential negative impacts of human activities on the environment. It identifies, analyzes, and evaluates risks associated with specific actions or substances to facilitate informed decision-making and minimize environmental damage [54]. ERA focuses on gauging the probability and severity of adverse effects on various ecosystems, encompassing terrestrial, aquatic, and atmospheric systems [55]. ERA finds application in various domains, including industrial activities, infrastructure development, chemical substances, genetically modified organisms, and pollution incidents. It plays a vital role in supporting sustainable development, guiding environmental management practices, and safeguarding ecosystems and human well-being. The fundamental steps involved in conducting ERA include hazard identification, exposure assessment, effects assessment, and risk management [54–56].

2.5 Environmental performance indicators

Environmental performance indicators (EPIs) are measurements used to evaluate and gauge the environmental performance of organizations, processes, products, or services [57]. They provide both quantitative and qualitative data, enabling the assessment, monitoring, and reporting of environmental impacts, resource usage, and sustainability endeavors. EPIs serve as valuable tools for tracking progress, establishing goals, identifying areas for enhancement, and communicating environmental performance to stakeholders. A wide array of environmental performance indicators can be utilized, depending on the specific context and objectives [58]. Some commonly employed EPIs encompass energy consumption, greenhouse gas emission, water usage, waste generation, recycling rate, biodiversity impact, environmental compliance, eco-efficiency, environmental expenditure, and certifications [57].

2.6 Green procurement

Green procurement, also known as sustainable procurement or environmentally responsible procurement, involves integrating environmental factors into the purchasing decisions of organizations. It aims to minimize the environmental impact associated with acquiring goods and services by considering criteria such as energy efficiency, resource conservation, waste reduction, pollution prevention, and the use of eco-friendly materials or technologies [59]. Implementing green procurement requires collaboration among stakeholders, including procurement departments, sustainability teams, suppliers, and top management [60]. It involves integrating environmental considerations into procurement policies, processes, and supplier selection criteria, as well as ongoing monitoring and evaluation of environmental performance. Green procurement includes key principles and strategies: environmental criteria integration, supplier evaluation, life cycle assessment, product certification and labels, and collaboration with suppliers [58, 61].

2.7 Environmental policy (EP)

Environmental policy refers to the actions taken by governments and organizations to address environmental challenges such as the Clean Air Act in the United States. These challenges are wide-ranging and include issues such as climate change, air pollution, and water pollution [62]. EP dates back to the early conservation movement of the nineteenth century. The first significant environmental policy was the creation of national parks in the United States in the late nineteenth century [63]. EP became more widespread in the twentieth century with the creation of the US Environmental Protection Agency in 1970 and the adoption of the Clean Air Act and Clean Water Act [9]. International organizations such as the United Nations have played a significant role in shaping environmental policies [64]. The UN Conference on the Human Environment, held in Stockholm in 1972, was a landmark event in the development of environmental policy at the international level [65]. The conference led to the creation of the United Nations Environment Program (UNEP) which played a leading role in shaping global environmental policy [66].

2.8 Current global environmental policies

2.8.1 International environmental policies

Efforts to protect the planet and tackle environmental problems rely heavily on international environmental policies. These policies play an essential role in preventing global pollution, propelling sustainable development, and conserving natural resources. The policies tackle an array of environmental issues, including biodiversity loss, climate change, and pollution. Through international conventions and agreements, countries collaborate to set goals, develop strategies for dealing with environmental threats, and establish regulations.

2.8.2 United nations framework convention on climate change

The United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992 and ratified by nearly all countries, exemplifies a significant international environmental policy to fight climate change, provides a solid foundation for global cooperation to stabilize greenhouse gases in the atmosphere and prevent harmful human interference with the fragile climate system that supports life. By adhering to the principles of the UNFCCC, nations join forces to create a sustainable and resilient future—minimizing the impact of climate change, safeguarding societies, and preserving ecosystems for future generations [67].

2.8.3 Kyoto protocol

The Kyoto Protocol, an offshoot of the UNFCCC, is a landmark in international efforts to counter the impending danger of climate change. Adopted in 1997 and fully operational in 2005, the Protocol advocates for mandatory reduction in emissions for developed countries, known as Annex I parties, from 2008 to 2012. The ultimate aim is to decrease greenhouse gas emissions substantially below 1990 levels, paving the way for a responsible and sustainable future. The Protocol incorporates innovative market-based emission trading systems that not only propel reduction efforts but incentivize greener practices. Though this protocol has gained success in stimulating global climate action awareness and laid the groundwork for future international frameworks, it is faced with several implementation challenges [68].

2.8.4 Paris agreement

Adopted in 2015 under the UNFCCC, the Paris Agreement represents a significant milestone in the fight against climate change. It aims to strengthen the global response and limit the rise in global temperatures to below 2 degrees Celsius above pre-industrial levels, ideally keeping it to 1.5 degrees Celsius. The Agreement necessitates commitments from all nations to heighten efforts in reducing greenhouse gas emissions, adapting to climate change impact, and providing support to developing countries. This agreement has been widely accepted however, it faces difficulties in absolute

compliance by some nations as it requires regular reviews of a country's progress towards meeting their climate-related goals [69].

2.9 National environmental policies

Countries adopt national environmental policies to tackle and alleviate pollution while mitigating its adverse impacts on the environment. These policies are tailored to each nation based on their unique environmental trials and priorities. This gamut of strategies could include regulations, laws, and programs aimed at reducing pollution, conserving our natural resources, and advocating for sustainable development. The pivotal role played by these policies ensures the safeguarding of ecosystems, biodiversity, and community welfare.

2.9.1 United States environmental protection agency (USEPA)

The USEPA, commonly referred to as the EPA supports and executes numerous environmental policies across America. Its fundamental goal focuses on tackling and mitigating issues of pollution, securing human health, and preserving the environment. The EPA relentlessly formulates and enforces a multitude of regulations and standards spanning not only air and water quality, hazardous waste disposal techniques, and chemical uses, but beyond. The plethora of efforts from the EPA vitally contributes to steering the U.S. toward a future that is cleaner, healthier, and more sustainable [70].

2.9.2 European Union environmental policy

One of the EU's environmental policy cornerstones is the shift toward a circular economy, bidding farewell to the traditional "take-make-dispose" linear economic model and welcoming a more sustainable one. The idea centralizes on PEM by optimizing product and material value, decreasing waste, and conserving resources. Further, the EU is resolute about curbing greenhouse gas emissions and battling climate change. By imposing strict regulations and goals, the EU encourages cleaner, more efficient energy systems, cuts down dependency on fossil fuels, and supports renewable energy. This commitment extends to research funding and financial incentives to promote sustainable technology adoption. The European Union (EU) holds a strong and inclusive environmental policy framework that is directed towards reducing pollution and championing sustainable growth. It includes a myriad of strategies, legislations, and regulations addressing various environmental dilemmas and challenges. These strategies target fundamental sectors like air and water quality, waste management, biodiversity protection, and climate change alleviation [71].

2.9.3 China's environmental protection policies

As a leading global economy, China acknowledges the absolute importance of effectively addressing the complex environmental challenges of recent times. China's assertive and inclusive environmental protection policies are framed to address urgent issues including air and water pollution control, energy preservation, and ecological restoration. The country has initiated a plethora of measures to drastically reduce industry and vehicle emissions, promote clean and renewable energy, and significantly improve waste management practices. By adhering to strict environmental impact assessments, encouraging public participation, and investing heavily in research, innovative technologies, and crucial infrastructure, China is firmly advancing towards a greener and more sustainable tomorrow [72].

2.10 Regional environmental policies

Regional environmental strategies are instrumental in mitigating pollution within distinct geographical zones by synthesizing efforts and creating harmonized frameworks for environmental stewardship among partnering nations. This collaboration facilitates a more effective counteraction to environmental issues common within the region. These strategies often give life to regional accords, statutes, and norms aimed at pollution abatement, garbage routing, conservation of resources, and the safeguarding of biodiversity. These policies function as a platform for nations to pool their resources, endorsing collective liability for environmental protection and sustainable development within their region.

2.10.1 African Union environmental policy

The African Union (AU) Environmental Policy is an overarching blueprint designed to address numerous urgent environmental matters across the expansive African continent. With an unwavering commitment to sustainable growth, preserving priceless natural wealth, and successful reduction of pollution, this policy stands as a promising beacon for Africa's environmental potential. It underscores the acute need for robust governance, human capital development, and regional collaboration to directly confront these environmental challenges. To ensure the desired effect of the AU Environmental Policy, the African Union engages intimately with its member states, enforces this vital blueprint, and bolsters it with a diverse array of initiatives [73].

2.10.2 Association of Southeast Asian Nations (ASEAN) environmental policy

The Association of Southeast Asian Nations (ASEAN) Environmental Policy was crafted to foster sustainable development and protect the environment within its member states. It aspires to make a substantial positive impact on environmental issues. The policy underlines the critical importance of tackling pollution with a complete and cooperative approach. By focusing intensely on key areas like air and water pollution regulation, effective waste management, biodiversity conservation, and climate change adaptation, ASEAN actively seeks to trigger decisive change. ASEAN states, through their united efforts, implement the policy by sharing best practices, conducting collaborative research, and creating regional frameworks and guiding policies [74].

2.11 Corporate environmental policies

By establishing guidelines and objectives, company environmental strategies exercise a pivotal role in pollution prevention by encouraging ventures to lessen their ecological footprint through PEM. These directives encapsulate pledges to sustainable practices, conservation of resources, and reduction in emissions. This details tactics for enhancing energy productivity, championing renewable energy resources, and decreasing waste production. Companies such as Toyota, Apple, and Walmart have developed strategies to create a purer environment and subdue the detrimental consequences of their business operations.

Toyota's Environmental Challenge 2050 proposes an exhaustive blueprint to tackle environmental dilemmas linked with automobiles and manufacturing. The policy sets forth six fundamental tasks: curbing CO_2 emissions, lessening water consumption, advocating recycling, directing attention to alternative fuel automobiles, safeguarding biodiversity, and encouraging a sustainable society. Toyota is dedicated to lowering vehicle emissions, directing capital towards electric and hydrogen fuel cell vehicle research and development, and envisioning a future devoid of CO_2 emissions [75]. Apple's environmental responsibility policy accentuates its firm dedication to curtailing its carbon footprint and conserving indispensable resources for the planet's welfare. This comprehensive policy is ardently centered around pioneering product design, meaningful energy efficiency, and ethical sourcing of materials. Leading the way, Apple intertwines renewable energy sources and state-of-the-art, energy-efficient technologies into their daily operations and superior product range. In their quest to reduce waste, Apple supports recycling programs, inviting the international community to pull together in the pursuit of a sustainable tomorrow. By guaranteeing responsible material sourcing, Apple looks to abolish hazardous substances and considerably diminish their environmental impact throughout its complicated supply chain [76]. Walmart's approach to sustainability, embodied in its policy, displays a resolute commitment to being good stewards of the environment, adopting an all-encompassing perspective on sustainability. Their unwavering focus on zero waste, capitalizing on renewable energy resources, and transforming the marketplace with a multitude of eco-friendly products illustrate their firm dedication. In addition to the policy which features grand and audacious goals, Walmart holds ambitions to curtail greenhouse gas emissions, amplify energy efficiency, and integrate renewable energy into its operational processes [77].

2.12 Gaps in current environmental policies

While a myriad of environmental policies exists, substantial loopholes persist, hindering effective pollution prevention and impeding sustainable environmental progression. Rooted in deficient enforcement strategies, inadequate funding for policy deployment, poor surveillance and reporting structures, and a lack of global consolidation and unison, these gaps demand urgent attention. The absence of robust enforcement mechanisms stands out as a prominent deficiency,

where outlined practices often fail to materialize due to lax execution and minimal penalties for contravention. This not only allows corporations and individuals to disregard environmental statutes but also leads to elevated pollution levels. Augmenting enforcement strategies is crucial to ensuring compliance and the efficacy of environmental policies. Furthermore, insufficient funding poses a considerable obstacle, limiting the capacity to enforce rules, construct eco-friendly infrastructure, and invest in research for pollution reduction. Overcoming this gap requires increased financial backing and resource allocation. Inadequate monitoring and reporting systems add to the challenge, making it formidable to pinpoint pollution sources and implement targeted strategies. Enriching monitoring technologies, installing robust reporting structures, and promoting transparency are indispensable steps to bolster policy effectiveness. Additionally, limited international cooperation and coordination, stemming from disparities in priorities and regulations, pose obstacles to combating pollution globally. To bridge this gap, reinforcing international consolidation mechanisms, setting shared objectives, and promoting discourse among nations are essential for a cohesive and effective approach to pollution prevention. By strengthening international agreements, enhancing national environmental regulations, promoting sustainable business practices, and investing in research and innovation, EP can be made more effective in mitigating environmental pollution [78, 79].

2.13 Statistical snapshots: data-driven analysis of global pollution challenges

A crucial connection exists between technology and the environment in today's fast-paced world. Data-driven analysis uncovers insights and trends using data to understand the significant pollution issues worldwide [80].

2.14 Air pollution

Air pollution threatens global health, from smog hanging over cities to smoke inside homes. According to a recent report [81] by the World Health Organization (WHO) on global air pollution, almost all of the global population (99%) is exposed to air pollution levels that put different populations across the globe at an increased risk for diseases, including heart disease, stroke, chronic obstructive pulmonary disease, cancer, and pneumonia. The WHO actively monitors exposure levels and health impacts, such as deaths and Disability-Adjusted Life Years (DALYs), attributable to national, regional, and global air pollution from both ambient (outdoor) and household sources. These estimates play a crucial role in official reporting, including the World Health Statistics and the Sustainable Development Goals. The air pollution data portal provided by the WHO reveals alarming statistics, indicating a burden of disease with 6.7 million deaths annually attributed to exposure to ambient and household air pollution. Additionally, household exposure remains a significant concern, with 2.3 billion people relying on polluting fuels and technologies for cooking as of 2021. *Strategies such as air quality monitoring, urban planning, education, legislation, and enforcement should be adopted with global cooperation to address the pervasive and severe impact of air pollution on public health worldwide* [81].

Table 1 Trends in global emissions: highlights from 24 countries (2012–2021)

Category	Data
Year	2022
Global fossil CO_2 emissions (Including Cement Carbonation)	10.0 GtC yr^{-1}
Regional changes in fossil CO_2 emissions (2022):	
China	Decrease: 0.9%
European Union	Decrease: 0.8%
United States	Increase: 1.5%
India	Increase: 6%
Rest of the world	Increase: 1.7%
Changes in emissions by source (2022):	
Coal	Change: 1.0%
Oil	Change: 2.2%
Gas	Change: – 0.2%
Emissions from 24 countries (2012–2021)	Decrease: 2.4 $GtCyr^{-1}$ (8.8 $GtCO_2$)
Deforestation contribution (2012–2021)	1.8 ± 0.4 GtC yr^{-1}
Atmospheric CO_2 concentration increase (2022):	51% above pre-industrial levels

2.15 Global carbon project

The global carbon project assesses anthropogenic carbon dioxide (CO_2) emissions and distribution among the atmosphere, ocean, and terrestrial biosphere providing an understanding of the global carbon cycle, shaping effective climate policies, and projecting future climate change. Recent data from the global carbon budget as summarized in Table 1 indicate that in 2022, global fossil CO_2 emissions, including cement carbonation, marginally exceeded pre-COVID-19 pandemic levels, registering at 10.0 GtC yr^{-1} (gigatons of carbon per year). Regionally, emissions experienced a 0.9% decrease in China and a 0.8% reduction in the European Union, while the United States, India, and the rest of the world saw increases of 1.5%, 6%, and 1.7%, respectively. The carbon project report indicated varied trends with coal, oil, and gas emissions exhibiting changes of 1.0%, 2.2%, and – 0.2%, respectively. Notably, fossil CO_2 emissions from 24 countries decreased during the decade 2012–2021, contributing about 2.4 GtC yr^{-1} (8.8 $GtCO_2$) to global emissions. Deforestation remains a key contributor, with emissions at 1.8 ± 0.4 GtC yr^{-1} over the 2012–2021 period. There is an urgent need for global emissions reduction efforts to align with climate targets. The concentration of CO_2 in the atmosphere in 2022 marked a 51% increase above pre-industrial levels [82]

2.16 Gas emissions

The Emissions Gap Report 2023, authored by the United Nations Environment Program (UNEP), indicated escalating challenges posed by greenhouse gas emissions, soaring temperatures, and intensifying climate impacts as summarized in Table 2. This report assesses the gap between pledged greenhouse gas (GHG) emissions reductions and those required to align with the long-term temperature goal of the Paris Agreement. In 2022, global greenhouse gas (GHG) emissions soared to an unprecedented record of 57.4 $GtCO_2e$, with fossil fuel combustion and industrial processes contributing a significant two-thirds of the total. Rapid increases in methane (CH4), nitrous oxide (N_2O), and fluorinated gases (F-gases) emissions added to the environmental challenge. Global net land use, land-use change, and forestry (LULUCF) CO_2 emissions remained steady. Based on existing policies of the Paris Agreement, progress has been made with a reduction in the projected increase of greenhouse gas emissions for 2030 from 16 to 3%, this highlights the urgency of addressing disparities in emissions contribution. *There is a need for immediate and accelerated mitigation actions to achieve the deep annual emission cuts necessary to narrow the emissions gap. This can be achieved by urging nations to accelerate low-carbon development transformations and developed countries to take more ambitious steps while supporting developing nations in their pursuit of low-emission growth* [83].

2.17 Water pollution

In 2021, the global water crisis persisted, affecting over 2 billion people in water-stressed countries, a situation expected to worsen due to climate change and population growth. Disturbingly, in 2022, at least 1.7 billion people globally utilized drinking water contaminated with feces, posing severe risks to public health. Microbial contamination from such sources is a primary threat to water safety, leading to diseases like diarrhea, cholera, dysentery, typhoid, and polio, causing an estimated 505,000 diarrheal deaths annually. While 73% of the global population (6 billion people) had access to safely

Table 2 Changes and trends in global greenhouse gas emissions

Category	Data
Global GHG emissions ($GtCO_2e$)	57.4
Contribution of fossil fuel combustion and industry	2/3 of total GHG emissions
Breakdown of GHG emissions by type	
Carbon dioxide (CO_2)	(Not specified)
Methane (CH_4)	Rapid increase
Nitrous oxide (N_2O)	Rapid increase
Fluorinated gases (F-gases)	Rapid increase
Global net LULUCF CO_2 emissions	Steady
Progress in GHG emissions reduction (2030)	Reduced projected increase from 16 to 3%

Table 3 Trends in the global water crisis and contamination

Category	Data
Year	2021 and 2022
Global water crisis (2021)	Affecting over 2 billion people in water-stressed countries
Drinking water contamination (2022)	1.7 billion people globally utilized drinking water contaminated with feces
Health risks from contamination:	Microbial contamination poses risks to public health, leading to diseases such as diarrhea, cholera, dysentery, typhoid, and polio, causing an estimated 505,000 diarrheal deaths annually
Access to safely managed drinking water (2022)	73% of the global population (6 billion people) had access
Disparities in access:	2.2 billion people lacked safely managed drinking water services

managed drinking water services in 2022, disparities persisted. The remaining 2.2 billion people lacked such services, facing issues ranging from basic access within a 30-min round trip to collecting water from unprotected sources [84]. These statistics as presented in Table 3 underscore the far-reaching consequences of drinking water on global health. *World Health Organization (WHO) plays a crucial role in global water quality, effective use of water quality guidelines and emphasis on health-based effects with provided regulations and frameworks for managing these risks globally should be adopted in various nations to tackle water pollution* [85].

2.18 Global pollution

The Lancet Commission on Pollution and Health disclosed that pollution accounted for a staggering 9 million premature deaths in 2015, emerging as the world's predominant environmental risk factor for both disease and premature mortality. This estimation has been revisited using data from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019, revealing that pollution continues to be responsible for approximately 9 million deaths annually as summarized in Table 4, translating to one in six global fatalities. While there have been declines in deaths associated with certain types of pollution linked to extreme poverty, the progress is counteracted by escalating deaths attributable to ambient air pollution and toxic chemical pollution, particularly lead. The unintended consequences of industrialization and urbanization have propelled a 7% increase in deaths from these modern pollution risk factors since 2015 and a staggering 66% surge since 2000 [86].

2.19 Synthesis of landmark studies

The incorporation of a diverse range of scholarly literature within this study served to elucidate the landscape of global environmental-conscious initiatives. This methodological approach helped to craft a coherent narrative and facilitate a critical assessment. This study adopts a holistic approach, this approach allows for a more open synthesis of information by providing an enriched perspective, understanding, and recommendations for the global issues of interest.

Taxing is pivotal in pollution control and sustainable development. Research on the Influence of taxation on the sustainable development goals for the year 2030 [87], explored the relationship between various taxes and sustainable development goals (SDGs). Findings indicated a positive association between taxes and SDGs; however, a singular tax type may not uniformly contribute to SDGs. This varies across countries and emphasizes the need for enhanced tax policies. *To address this, a careful environmental tax policy design specific to various countries with consideration of broader socio-economic implications should be implemented globally*. Ecological development and green technology are crucial

Table 4 The global impact of pollution on premature mortality

Category	Data
Total premature deaths due to pollution (2015)	9 million
Annual deaths due to pollution (current estimate)	Approximately 9 million annually
Global impact of pollution	One in six global fatalities
Trends in modern pollution risk factors (since 2015)	7% increase in deaths since 2015, 66% surge since 2000

factors driving the prevention of environmental pollution globally. The relationship between green investment, natural resources, green technology innovation, and economic growth has been shown to have an impact on the ecological development and footprint in China [88]. Findings indicate a significant positive short- and long-term association between these factors and the ecological footprint. Implementing environmental policies such as green investment, rigorous regulations on natural resource rent, and fostering green technology innovation for optimal efficiency will help minimize environmental pollution globally.

2.20 Unraveling CO_2 emission dynamics: alternative policies and regional perspectives

Recent studies have raised concerns about the possible influence of information and communication technologies (ICTs) on environmental pollution. A study by [89] showed that ICTs increase carbon dioxide (CO_2) emissions, contributing to environmental issues. This can be addressed by good policies and effective legal systems for environmental protection, legal systems crucially contribute to the mitigation of carbon emissions [90]. Land freight structures such as rail and road freight share have reportedly contributed to the intensity of carbon emission globally [91]. Ref. [92] An assessment of the impact of freight structures on carbon emissions in 16 Chinese provinces revealed that freight structures indirectly affect CO_2 emissions through the scale effect, which necessitates various nations to introduce region-specific carbon reduction strategies to minimize global pollution. Urban development is also crucial to environmental quality, urban agglomerations have been found to have a higher impact on CO_2 emissions in upper-middle-income countries resulting in overconcentration and urban sprawl. These challenges in middle-income countries contribute to several global environmental challenges, enhanced urban policies, particularly in upper-middle-income economies, improved infrastructure, efficient transportation, and stringent regulations on infrastructure development will be significant in addressing these challenges. Transportation, industrialization, and urbanization are major drivers of environmental pollution [93]. To address the escalating global concern over environmental pollution propelled by these factors, there is a need to minimize population-driven environmental degradation through efficient energy usage awareness, renewable energy investments, and green innovation.

Many countries around the globe have tackled environmental pollution using commercial policies such as export tax policies by implementing expansionary and contractionary commercial policies. A study [94] in Australia introduced a novel viewpoint by merging environmental economics with commercial policies. This research showed the repercussions of CO_2 emissions (CO_2e) over 42 years within the Australian context revealing a positive long-term association between expansionary commercial policy and CO_2e. Conversely, contractionary commercial and monetary policies demonstrate effectiveness in mitigating CO_2e. *From these findings, it is necessary to formulate environmentally conscious commercial and monetary policies, advocating for higher export taxes on environmentally detrimental industries and incentives for cleaner technologies.* Also, considering the environmental implications of remittances and fossil fuels, the integration of green consumption programs can be very significant in minimizing global pollution and sustainable development. However, there is a need to explore alternative policies and diverse regions to understand the relationship between commercial policies and CO_2e [95, 96].

2.21 Tailoring policies for sustainable growth in the face of environmental challenges

Innovations in green energy, natural resources, and environmental policy are significant in managing environmental pollution. In a pioneering effort to examine the causal impact of green energy innovations (GENI), natural resources (NRSS), and environmental policy (ENPY) on sustainable growth and energy transition in the US [97], advocates for an environmentally friendly economic growth, a positive impact of environmental policies in promoting sustainable growth and energy transition. *By bolstering policies that promote the responsible utilization of natural resources and encourage innovations in green energy, providing tax incentives for environmentally conscientious businesses, and addressing the environmental externalities associated with manufacturing firms, nations can effectively mitigate environmental degradation. However geographical consideration is a major limitation in implementing these strategies, this can be addressed through regional customization tailoring policies to the unique characteristics and needs of different geographical areas.*

In recent times, there have been several international, national, regional, and corporate environmental policies, however, pollution is still on the rise due to the ineffectiveness and implementation challenges. *The ineffectiveness of environmental policies lies with the challenge of policymakers encountering dated information, personal experiences, and individual observations, this can be addressed through policy evaluation, data reliability, and stakeholder engagement in achieving a balance between development and environmental protection* [98]. The process-based technical framework

for policy environmental impact assessment (PB-EIA) approach presents practical and systematic methods to evaluate the environmental impact of policies. A recent study [99] applied PB-EIA to the use of wastewater resources in China. Findings showed constraints in the policy's formulation and implementation, tied to institutional, technological, and economic factors, with identified negative environmental impacts related to energy consumption and carbon emissions. *Application of the PB-EIA framework to real-world cases will help mitigate environmental policy failures, shedding light on the complex interplay of factors influencing policy outcomes*.

2.22 Balancing act: mitigating unintended consequences in pollution control policies

Research has indicated that conducting thorough impact assessments before enacting policies is a crucial approach to mitigating unintended consequences [100]. These assessments evaluate environmental effects by considering social, economic, and health implications. Mitigating potential trade-offs and unintended consequences associated with pollution control policies requires a refined approach. Drawing insights from a study by [101] on the analysis of urban green and blue space interventions, a successful strategy involves understanding the complexity of the social-ecological system influenced by pollution control measures. To avoid potential trade–offs, clear articulation of policy objectives and consideration of diverse stakeholder perspectives by including industry representatives, environmental groups, and affected communities, in the policymaking process and, regular monitoring and evaluation, ensure the adaptability of policies over time. Public awareness, engagement, and collaboration between institutions also contribute to the success of pollution control initiatives or industry displacement [86].

2.23 Promoting sustainable consumption: strategies for source-based pollution mitigation

Plans for sustainable consumption are vital to combat pollution at its inception to lessen the negative ecological impact generated by consumption habits, which have profound ramifications for our planet. The adoption of sustainable consumption habits by individuals and organizations can shrink the global carbon footprint and contribute to creating an environmentally responsible society. Central to these strategies is the emphasis on promoting knowledge and understanding, fostering understanding of the importance of sustainable consumption and the ramifications of individual choices. Initiatives such as awareness campaigns, forums, and programs play a pivotal role in enabling individuals to explore avenues for minimizing their environmental impact and championing eco-friendly lifestyles [102]. Additionally, integrating sustainability education into school curricula emerges as a crucial measure to instill environmentally conscious morals from an early age [103]. Another significant tactic is policy creation and enforcement. Government bodies can hugely influence the promotion of sustainable consumption by introducing eco-focused regulations and policies. Methods such as taxing high carbon-emission products, subsidizing renewable energy and advocating businesses to utilize sustainable production techniques can tip the balance towards a greener society and lifestyle [104].

Integral to the sustainability journey are technological advancements and innovation, serving as pivotal drivers. Progress leads to the creation of novel solutions addressing pollution. These technological strides not only tackle environmental challenges but also pave the way for more sustainable goods and services such as electric vehicles, renewable energy sources, and eco-friendly materials. Endorsing and investing in these areas accelerates the shift toward a more sustainable economy, thereby diminishing our environmental impact [105]. Also, it is recommended to offer businesses and consumers incentives or subsidies for adopting sustainable measures or opting for eco-friendly products. The establishment of reward programs serves as an additional means to cultivate behaviors aligned with responsible consumption [106].

2.24 Managing synergies and conflicts between economic agreements and global environmental policies for pollution control

Balancing economic development and environmental sustainability while addressing potential conflicts between economic agreements and global environmental policies is very vital in pollution prevention and control. Policymakers can pursue this goal by embedding environmental policies and standards into trade agreements by ensuring participating countries comply with pollution control measures. It is vital to establish a framework motivating countries to exceed environmental standards, fostering a race toward higher standards rather than a race to the bottom. The policies should remain adaptable, and regularly reviewed and coherence between national and international economic and environmental policies must be maintained to avoid contradictions that could undermine pollution control efforts [107]. In

addition, policymakers should consider making trade agreements with a specific focus on advancing green and sustainable practices. These agreements can offer incentives for adopting environmentally friendly technologies, renewable energy sources, and sustainable resource management. Implement mechanisms and standards that reward countries for adopting and enforcing stringent pollution control measures [108]. Once standards are set, a robust monitoring system should be established to ensure countries adhere to both trade and environmental agreements. Effective enforcement measures, including penalties for non-compliance, are essential to dissuade countries from neglecting their environmental responsibilities. Moreover, incentives or rewards should be provided to businesses and countries that exceed pollution control standards [109]. Also, engaging various stakeholders, such as environmental organizations, businesses, and local communities, is critical in the negotiation and implementation of trade and environmental policies. This inclusive approach fosters collaboration, considering the diverse perspectives and needs of different groups [110].

3 Holistic approaches to addressing global environmental pollution

1. Diagnosis of pollution hotspots, processes, and systems: One of the primary methods for diagnosing pollution hotspots is through the collection and analysis of data on pollutants in the environment by monitoring the levels of pollutants in air, water, and soil, as well as tracking emissions from industrial processes and transportation sources. By analyzing this data, researchers can identify patterns and trends in pollution levels and determine where pollution hotspots are likely to occur [111]. Another method for diagnosing pollution hotspots is through the use of modeling tools and on-the-ground assessments of the physical and social conditions in a given area by examining the distribution of industrial facilities and transportation routes, as well as assessing the health and economic impacts of pollution on local communities [112].
2. Swift interventions in reducing wastes at source: This can be achieved through a variety of methods such as extended producer responsibility programs, which require manufacturers to take responsibility for the environmental impacts of their products [113]. Another strategy is to reduce the use of single-use plastics and other disposable items, using reusable containers and packaging, and adopting sustainable procurement practices that prioritize products with minimal packaging made from recycled materials [114].
3. Elevating the yield and quality of products by optimizing production processes, is done by analyzing the steps involved in production and identifying areas where efficiencies can be gained and waste can be minimized. By streamlining processes, reducing downtime, and improving production flow, manufacturers can increase their output without increasing their resource consumption [115]. Implementing quality control measures is also critical to elevating the yield and quality of products, this involves the establishment of standards for product quality and ensuring that products meet these standards through regular inspections and testing [116].
4. Value addition to products through product innovation by developing new product features, and technologies that improve performance, and functionality and creating entirely new products that meet emerging customer needs and emission standards [117].
5. Integration of concerns of stakeholders on environmental initiatives by dialoguing with stakeholders and seeking inputs and feedback on environmental initiatives and policies. This involves conducting surveys, focus groups, or other forms of consultation to understand stakeholder perspectives and concerns, as well as soliciting feedback on proposed environmental initiatives [118].
6. Integration of economic concerns of stakeholders in rolling out policies by conducting a thorough economic impact assessment, analyzing the potential costs and benefits of an initiative, as well as the potential risks and opportunities for different stakeholders. This information can be used to influence decision-making and ensure that policies are designed in a way that maximizes economic benefits and minimizes negative environmental impacts [119].
7. Rolling out environmental action programs by developing and implementing strategies to address environmental issues and concerns. These programs typically involve a series of actions, policies, and initiatives aimed at reducing the negative impact of human activities on the environment and promoting sustainable practices. In rolling out environmental action programs, the following steps should be considered; Identifying the environmental issue, conducting research and analysis to understand the root cause of the problem, its scope and impact, and potential solutions, developing a plan of action, engaging stakeholders by involving diverse groups and implementation of plan followed by monitoring and evaluation of progress [120].
8. International environmental cooperation: International environmental cooperation is the collaboration and coordination between countries, international organizations, and other stakeholders to address global environmental

issues [121]. International environmental cooperation is essential for addressing global environmental challenges, as many environmental issues such as climate change, biodiversity loss, and ocean pollution are transboundary and cannot be solved by individual countries acting alone. This can be achieved by sharing of knowledge, resources, and best practices to develop effective policies and programs [122].

9. Public accessibility of environmental information from authorities, is essential for ensuring transparency and accountability in environmental decision-making processes. It also enables public participation in environmental governance by allowing citizens to make informed decisions and contribute to environmental policy-making [123].
10. Improving the efficiency of existing controls by optimizing the effectiveness and cost-effectiveness of measures and regulations designed to protect the environment including strategies to improve the implementation of existing regulations, streamline enforcement processes, and enhance monitoring and reporting mechanisms. Existing environmental controls can be improved through risk-based approaches (targeting enforcement efforts on activities that pose the highest environmental risks by prioritizing high-risk activities) and performance-based approaches (setting performance standards for specific sectors, and allowing flexibility in how those standards are achieved), compliance assistance (providing support and guidance such as technical assistance and training programs to businesses to help them comply with environmental regulations.) and Regulatory reform (reviewing and updating existing regulations to ensure they are effective, efficient, and up-to-date by removing redundant or outdated requirements, streamlining approval processes, and improving the clarity and transparency of regulations) [124].
11. Installation of technologies to control pollution: Pollution control technologies are designed to improve the efficiency and effectiveness of industrial processes, reduce waste and emissions, and protect the environment and human health [125]. Air pollution control technologies such as particulate control systems, electrostatic precipitators, and scrubbers could be applied to remove pollutants from industrial exhaust gases [126], water pollution control technologies including wastewater treatment systems, sedimentation tanks, and filtration systems can be used to remove pollutants from industrial wastewater before it is discharged into the environment [127] and solid waste management technologies such as recycling and composting systems, landfill liners, and leachate treatment systems can be used to reduce the amount of waste generated and manage the disposal of waste [125, 128]. Also, hazardous waste management technologies such as incinerators, chemical treatment systems, and stabilization and solidification processes should be designed to safely manage and dispose of hazardous waste [129].
12. Efficient system of taxation on municipal waste disposal and effective landfill location and management [124, 130]. The imposition of fees or taxes on the disposal of municipal waste can create economic incentives for individuals and businesses to reduce waste generation and increase recycling and reuse, which can help to conserve natural resources and reduce greenhouse gas emissions. Proper landfill siting and management by using engineered liners and caps, proper waste placement, and compaction. Factors such as geology, hydrology, and proximity to sensitive areas should be considered for proper siting of landfills [131].
13. Switching to more advanced technologies as a replacement for existing pollution control techniques, by using newer and more efficient technologies to reduce pollution in industrial processes. These technologies should be designed to replace older, less effective pollution control techniques, which may be less efficient or effective at reducing pollution [132].
14. Strict adherence and application of the principles of the Stockholm declaration in all various nations [133]. This includes safeguarding natural resources and wildlife at all cost, eliminating of weapons of mass destruction, sharing and preventing the exhaustion of non-renewable natural resources, assisting developing countries to tackle pollution, preventing of damaging pollution in oceans, eliminating environmental problems by planning human settlements, application of science and technology to improve the environment, making essential environmental education, appropriate policies by governments, promotion of environmental research in developing countries, international cooperation on environmental issues, safe exploitation of resources by states in order not to endanger others and establishment of national standards by each nation [130, 134].
15. Transitioning to a Circular Economy: The goal of transitioning to a circular economy model is to minimize waste and maximize the efficient use of resources [135]. This involves reducing the consumption of raw materials, promoting recycling and reuse, and designing products to last longer and be recyclable. By doing so, pollution associated with extraction, production, and disposal can be reduced [136].
16. Promoting environmental education and awareness by integrating environmental education into school curricula, conducting awareness campaigns, and fostering a sense of responsibility and stewardship among communities [137].

17. Restoring and Conserving Ecosystems by rehabilitating degraded ecosystems and establishing protected areas to preserve crucial habitats [124].
18. Prioritizing green infrastructure and urban planning by developing green spaces, urban forests, green roofs, and sustainable transportation systems, which can contribute to pollution mitigation and, improve air and water quality [124].
19. Encouraging research and innovation to discover new solutions to global environmental challenges [138]. This can be achieved by supporting scientific research, technological advancements, and interdisciplinary collaborations to develop cleaner technologies, alternative energy sources, and more effective methods for controlling pollution [124].
20. Promoting corporate and social responsibility by encouraging businesses to adopt sustainable practices, reduce pollution in their operations, and promote transparency and accountability, which can significantly impact global environmental pollution [139].

4 Future perspectives

One potential area of growth in environmental policy is the use of technology to address environmental challenges such as advances in water treatment technologies. This includes innovations in renewable energy, energy storage, carbon capture, and storage could play an important role in reducing greenhouse gas emissions. As the global community continues to recognize the urgency of addressing environmental pollution, policy frameworks are expected to evolve and become more stringent, incorporating insights from ongoing research and global collaborations. The integration of advanced technologies such as artificial intelligence, remote sensing, and data analytics into environmental monitoring and management is anticipated to enhance the accuracy and efficiency of pollution control efforts.

5 Summary and conclusion

The escalating challenge of global environmental pollution demands urgent and collaborative action. This review highlights the varied nature of pollution, encompassing air, water, soil, and noise pollution, each contributing to environmental degradation and public health crises. Industrial activities, transportation, and agricultural practices are identified as principal anthropogenic culprits, necessitating the adoption of cleaner technologies, sustainable farming, and enhanced waste management practices. The implementation of preventive environmental management (PEM) and stringent environmental policies (EP) emerges as a pivotal strategy in combating pollution. Notably, the paper highlights the success of China's green growth due to rigorous EP enforcement, reflecting the potential for substantial improvements in environmental technology and policy. The review also recognizes the inherent challenges in policy implementation, marked by constraints such as non-compliance, economic barriers, and insufficient international cooperation. Despite these obstacles, the paper advocates for innovative solutions like satellite imaging for pollution monitoring, international research collaborations, and the formulation of global environmental indices to assess and enhance the efficacy of pollution management. This study recommends a holistic approach that aligns with sustainable development goals, urging nations to adopt and enforce comprehensive EPs and PEMs. While recognizing the complexity of global governance in environmental matters, there is a need for the role of institutional quality, well-formulated policies that are sensitive to national sovereignty yet effective on a global scale. Ultimately, these concerted efforts can lead to a significant reduction in pollution, fostering a healthier planet for current and future generations.

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Data Availability Not applicable.

Declarations

Consent for publication All authors participated in the development of the manuscript and consent to publication.

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