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Article

Environmental Policy Stringency, Air Quality, and Human Health in the Context of Sustainable Development: Evidence from Europe and Africa

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Abstract: Air pollution remains a major global environmental and public health challenge, with fine particulate matter ($PM_{2.5}$) contributing substantially to premature mortality. Environmental policy stringency is increasingly used to reduce emissions and population exposure, yet its effectiveness varies across institutional and economic contexts. This study examines the relationship between environmental policy stringency and $PM_{2.5}$ exposure, and its implications for human health, through a comparative analysis of Germany and France in Europe and South Africa and Kenya in Africa. Results reveal marked regional disparities. Germany and France exhibit high policy stringency scores of approximately 5.5 and 5.1, respectively, alongside $PM_{2.5}$ exposure levels of around 10 μg/m^3 in 2020. In contrast, South Africa and Kenya experience exposure levels near 24 μg/m^3, more than twice those observed in the European countries. Germany also reduced $PM_{2.5}$ exposure by more than 15% between 2010 and 2020, coinciding with stronger environmental regulation, renewable energy investment, and effective enforcement. Overall, stringent environmental policies are associated with improved air quality and reduced population exposure, but their effectiveness depends on governance quality, institutional capacity, energy-system characteristics, and regulatory enforcement. The findings emphasize context-sensitive environmental governance, stronger institutional capacity, effective regulatory implementation, and clean-energy transitions to improve air quality and public health.

Keywords: Environmental Policy Stringency; Human Health; Burden of Disease; $PM_{2.5}$ Pollution; Air Quality Governance; Climate Policy

1. Introduction

Air pollution is one of the most significant public health and environmental challenges we face in the world today [1]. Millions of people die prematurely each year due to diseases aggravated or caused by air pollution [2]. Of the myriad pollutants in the air, fine particulate matter, or $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 micrometers), is especially harmful [3]. Due to their small size, fine particles can enter the lungs and even the bloodstream or other parts of the body [4]. $PM_{2.5}$ exposure is strongly associated with heart disease, stroke, lung cancer, and other chronic respiratory diseases [5]. According to the World Health Organization, no level of $PM_{2.5}$ exposure can be considered entirely safe, highlighting the need for countries to continuously reduce ambient $PM_{2.5}$ concentrations [5]. Beyond its environmental implications, $PM_{2.5}$ represents a major public health concern because prolonged exposure increases the risk of cardiovascular disease, stroke, chronic respiratory diseases, lung cancer, and premature mortality. Consequently, improvements in air quality achieved through effective environmental policies have important implications not only for environmental sustainability but also for population health and healthcare systems.

At the same time, climate change presents an additional dimension to the worldwide crisis [6]. Increasing greenhouse gas emissions, primarily from fossil fuel combustion (coal, oil, and gas), are heating the globe and leading to extreme weather events [7]. Climate policies can also lead to the reduction of local air pollution. For example, substituting renewable power for coal-fired power will decrease greenhouse gas (considered global pollutants) and particulate matter (considered local pollutants) [8]. This "dual benefit" underscores why climate and environmental policies are increasingly viewed as essential policy tools rather than simply global public goods. Measures that reduce greenhouse gas emissions, such as the transition from fossil fuels to renewable energy, can simultaneously lower concentrations of local air pollutants, enabling policymakers to address immediate public health risks while advancing long-term climate mitigation objectives [9].

Over the past decades, several countries characterized by robust regulatory frameworks and effective enforcement mechanisms have achieved significant and sustained reductions in ambient air pollution levels [10]. In contrast, other countries maintain environmental legislation in formal terms but lack the institutional capacity or political commitment necessary for consistent enforcement, resulting in persistently elevated concentrations of $PM_{2.5}$ and other harmful pollutants. In many cases, governments may express policy intentions to address air pollution and climate-related challenges; however, limited financial resources, technological constraints, and weak institutional infrastructures hinder the effective implementation of regulatory measures [11–14]. These disparities raise an important analytical question: whether the presence of stringent environmental and climate policies alone is sufficient to improve air quality outcomes, or whether their effectiveness is contingent upon broader national contexts, including governance capacity, economic resources, and institutional strength.

The central proposition of this study is that the relationship between environmental policy stringency and air quality outcomes is context dependent and should be interpreted as an association rather than direct evidence of causality (**Figure 1**).

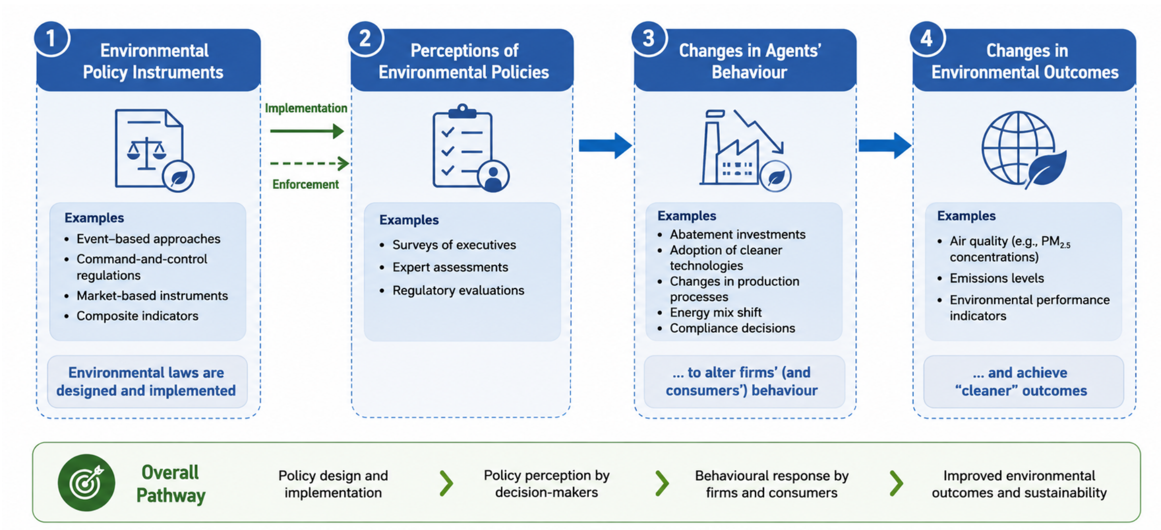

Figure 1. Conceptual pathway linking environmental policy stringency to environmental outcomes [15].

The extent to which stringent policies translate into reductions in $PM_{2.5}$ concentrations depends on factors such as institutional strength, economic structure, and enforcement capacity. Countries with high scores on the Environmental Policy Stringency index, such as Germany and France, benefit from well-developed regulatory institutions and sustained investment in environmental governance, enabling significant mitigation of $PM_{2.5}$ emissions [16]. By contrast, countries with weaker institutional frameworks or economies that remain structurally dependent on fossil fuels, such as South Africa and Kenya, face greater challenges in achieving similar reductions in particulate pollution despite the presence of formal environmental policies.

To guide the empirical analysis, this study addresses three research questions:

1. Are higher Environmental Policy Stringency (EPS) scores associated with lower levels of $PM_{2.5}$ exposure? This question examines whether stronger environmental regulations, as measured by the OECD EPS index, correspond to measurable improvements in ambient air quality.
2. How does the relationship between policy stringency and air quality differ between European and African contexts? This question explores how differences in economic development, industrial structure, and governance capacity influence the effectiveness of environmental policies.
3. What policy lessons emerge from the comparative analysis of environmental policy implementation and air quality outcomes across the selected European and African countries?

Through these questions, the paper aims not only to confirm the importance of stronger environmental and climate policies but also to identify the conditions under which such policies are most effective. The comparative analysis of Germany, France, South Africa, and Kenya highlights both the opportunities and the challenges associated with translating environmental policy into improved air quality outcomes. The findings also underscore the importance of international collaboration in supporting developing countries through capacity-building initiatives, financial mechanisms, and technological assistance aimed at strengthening climate governance and air pollution mitigation efforts [17].

While previous studies have examined the relationship between environmental policy stringency and greenhouse gas emissions, comparatively fewer studies investigate the effects of policy stringency on local air pollutants such as $PM_{2.5}$, particularly in cross-regional comparisons between developed and developing economies. This study contributes to the literature by examining how environmental policy stringency interacts with institutional capacity and energy structures to influence air quality outcomes across European and African contexts.

2. Literature Review

The relationship between environmental policy and air quality has been widely examined in environmental economics and policy research. A large body of literature demonstrates that regulatory interventions, such as emissions standards [18], carbon pricing mechanisms [19], and environmental taxation [20], can significantly reduce pollution levels and improve public health outcomes. In the absence of regulatory frameworks, economic actors typically externalize environmental costs, leading to higher levels of pollution from industrial activity, transportation, and household energy use. Consequently, government intervention is widely regarded as a central mechanism for correcting these market failures and promoting cleaner environmental outcomes.

The Environmental Policy Stringency (EPS) Index developed by the OECD measures the extent to which environmental policies impose explicit or implicit costs on environmentally harmful activities [15]. The composite index ranges from 0 (least stringent) to 6 (most stringent) and incorporates both market-based instruments, such as carbon taxes and emissions trading systems, and non-market measures, including emission standards and technology requirements. **Table 1** presents the 2020 EPS scores for the European case studies included in this research.

Table 1. Environmental Policy Stringency (EPS) scores for the European case studies based on the OECD Composite EPS Index (2020).

Country	Environmental Policy Stringency (EPS) Score (0–6)	Interpretation
Germany	5.5	Very high policy stringency
France	5.1	Very high policy stringency

As shown in **Table 1**, both Germany and France exhibit very high levels of environmental policy stringency, with EPS scores of approximately 5.5 and 5.1, respectively. These values indicate comprehensive environmental regulatory frameworks supported by a combination of market-based and command-and-control policy instruments. Their consistently high EPS scores provide the basis for selecting these countries as European case studies and enable subsequent comparison with South Africa and Kenya, where directly comparable OECD EPS data are unavailable. This comparison allows the study to explore how differences in environmental governance relate to observed variations in $PM_{2.5}$ exposure while acknowledging differences in institutional capacity and economic structure.

Empirical research using the EPS framework consistently finds that countries with higher levels of environmental policy stringency tend to achieve greater reductions in greenhouse gas emissions and local air pollutants [21].

These findings suggest that policy design and regulatory enforcement play a critical role in shaping environmental outcomes.

Evidence from European countries provides some of the strongest support for this relationship. Germany and France, for example, consistently rank among the countries with the highest EPS scores within the OECD [15]. Both countries have implemented comprehensive environmental policy portfolios over several decades, including renewable energy subsidies, vehicle emissions standards, and participation in the European Union Emissions Trading System [22]. Germany's Energiewende policy has accelerated the expansion of renewable energy through feed-in tariff mechanisms, while France has combined nuclear energy development with climate and transport regulations aimed at reducing emissions. Empirical studies indicate that the EU ETS has contributed to measurable reductions in emissions and improvements in air quality across participating countries [23]. However, the literature also emphasizes that the impacts of environmental policies often occur with temporal delays, as industrial sectors require time to adopt cleaner technologies and infrastructure systems gradually transition away from fossil fuels.

In contrast, the literature on air quality governance in African countries highlights a more complex and uneven policy landscape. Previous studies indicate that policy implementation in South Africa remains constrained by continued coal dependence and enforcement challenges, whereas Kenya's air pollution is primarily associated with transport emissions, biomass combustion, and waste burning. These findings demonstrate that policy effectiveness depends on national institutional and economic contexts rather than policy adoption alone [24,25]. These findings illustrate that the sources and dynamics of air pollution differ significantly across developing economies, requiring policy responses tailored to local economic and institutional conditions.

Another challenge identified in the literature concerns the availability and reliability of air quality data. European countries typically operate dense networks of ground-based monitoring stations, enabling detailed assessment of pollution levels and policy impacts [26]. In contrast, many African cities lack comprehensive monitoring systems, forcing researchers and policymakers to rely on satellite data and modeled estimates to approximate exposure levels. This data gap complicates efforts to evaluate the effectiveness of environmental policies and limits the evidence base available for policy design.

Despite the growing body of research on environmental policy stringency, most empirical studies focus primarily on greenhouse gas emissions rather than local air pollutants such as $PM_{2.5}$. Moreover, cross-regional comparisons examining how policy effectiveness varies across different institutional and economic contexts remain limited. In particular, there is relatively little comparative research exploring how environmental policy stringency interacts with governance capacity, energy structure, and enforcement mechanisms in African countries.

This study contributes to addressing this gap by providing a comparative analysis of environmental policy stringency and $PM_{2.5}$ exposure in two European countries (Germany and France) and two African countries (South Africa and Kenya). By examining cases characterized by different institutional capacities, economic structures, and energy systems, the study seeks to provide new insights into the contextual factors that shape the effectiveness of environmental policy in improving air quality outcomes.

3. Data and Methodology

The study applies a comparative descriptive analysis combining policy indicators and air quality exposure data across selected countries. It relies on secondary data obtained from internationally recognized datasets widely used in environmental and policy research. Secondary data are appropriate for cross-country comparative analysis because they provide standardized indicators that enable consistent measurement across national contexts and over time. Collecting primary data on air quality and environmental policy implementation across multiple countries would require extensive monitoring infrastructure and long-term field research that is beyond the scope of this study. Instead, this research utilizes established datasets compiled by international organizations, including the Organization for Economic Co-operation and Development [23], the World Bank, and the Global Burden of Disease project [27], which provides harmonized data suitable for comparative empirical analysis.

3.1. Data Sources

The principal indicator used to measure environmental regulatory strength is the Environmental Policy Stringency (EPS) index developed by the OECD [23]. The EPS index quantifies the degree to which environmental policies impose costs on environmentally harmful activities, thereby incentivizing reductions in pollution. The index ranges from 0 to 6, where higher values indicate more stringent environmental regulations. The EPS index incorporates both market-based instruments, such as carbon taxes, emissions trading systems, and renewable energy subsidies, and non-market regulatory measures, including emission standards, technology requirements, and other forms of environmental regulation.

EPS data are available for OECD member states and selected partner economies for the period 1990–2020 [16]. In this study, Germany and France are selected as European cases due to their consistently high EPS scores and well-developed environmental governance frameworks. South Africa and Kenya, although not included in the OECD EPS dataset, are incorporated in the analysis through descriptive comparisons of air quality indicators and national policy contexts. Accordingly, the analysis adopts a mixed comparative approach, combining quantitative comparisons where standardized indicators are available with qualitative interpretation where comparable policy indicators are not available.

This comparative approach enables an examination of how differences in policy stringency and institutional capacity relate to air quality outcomes across European and African contexts. To provide additional contextual understanding of environmental governance in the African case studies, the analysis also draws upon published literature and reports from regional and international organizations describing environmental policy implementation and enforcement. These sources complement the OECD EPS framework by providing qualitative evidence on institutional capacity, regulatory implementation, and environmental governance in contexts where standardized EPS indicators are unavailable.

Air quality is measured using population-weighted exposure to fine particulate matter, expressed in micrograms per cubic meter (μg/m^3). $PM_{2.5}$ is widely recognized as one of the most important indicators of ambient air pollution due to its well-established links to cardiovascular and respiratory diseases. The World Health Organization uses $PM_{2.5}$ concentrations as a key benchmark for assessing air quality and associated health risks.

$PM_{2.5}$ data are obtained from the World Bank's World Development Indicators and the Global Burden of Disease database [28], which combine satellite observations, ground-based monitoring data, and atmospheric modeling to estimate national average exposure levels. These datasets are commonly used in global air pollution studies because they provide consistent estimates for countries where monitoring infrastructure may be limited. Data was compiled and visualized using publicly available platforms such as Our World in Data. For illustration, population-weighted $PM_{2.5}$ exposure in 2020 was approximately 10 μg/m^3 in Germany and France, and 24 μg/m^3 in South Africa and Kenya [28], highlighting substantial differences in air quality outcomes across the selected cases.

3.2. Case Selection

Four countries were selected to enable comparison between developed and developing contexts characterized by different levels of environmental policy stringency, institutional capacity, and energy system characteristics. These countries are: Germany and France in Europe, and South Africa and Kenya in Africa. Germany and France are members of the Organization for Economic Co-operation and Development and represent high-income economies with relatively advanced environmental governance systems. Both countries maintain high scores on the Environmental Policy Stringency (EPS) index developed by the OECD, which measures the rigor of environmental regulations across countries [16]. Over the past decades, these countries have implemented comprehensive policy instruments, including renewable energy expansion [29], stringent vehicle emission standards [30], and participation in the European Union Emissions Trading System [31], which have contributed to sustained reductions in air pollution and $PM_{2.5}$ concentrations approaching the guideline levels recommended by the World Health Organization [5].

Although standardized OECD Environmental Policy Stringency (EPS) scores are unavailable for South Africa and Kenya, these countries were intentionally selected to provide a comparative perspective on how different institutional, economic, and energy-system contexts influence air quality outcomes. Accordingly, the comparison is interpretative rather than a direct quantitative comparison of EPS values across all four countries.

3.3. Contextual Explanatory Variables

To facilitate meaningful cross-country comparisons, the study considers several contextual factors that are known to influence air quality outcomes. Because this research adopts a comparative descriptive approach rather than a statistical modeling framework, these factors are not treated as statistical control variables. Instead, they provide contextual information for interpreting differences in $PM_{2.5}$ exposure and environmental policy effectiveness across the selected countries.

- **GDP per capita:** Economic development influences environmental outcomes through technological capacity, regulatory enforcement, and environmental investment. The relationship between income and pollution is often described by the Environmental Kuznets Curve, which suggests that pollution may initially increase during industrialization before declining as economies become wealthier and adopt cleaner technologies [32].
- **Energy mix:** The composition of national energy systems strongly affects air quality. Countries heavily dependent on coal or biomass typically experience higher particulate pollution levels than those relying on renewable energy or natural gas. South Africa's coal-based electricity system contributes significantly to its elevated $PM_{2.5}$ concentrations, while Kenya's electricity mix includes a large share of geothermal and other renewable sources [33].
- **Industrial structure:** Countries with large heavy-industry sectors, such as steel, mining, and cement, tend to exhibit higher baseline emissions. In contrast, economies dominated by service sectors typically generate lower industrial pollution levels. Germany and France have gradually shifted toward service-oriented economic structures, whereas South Africa maintains a substantial industrial base [34].

These contextual factors provide the analytical framework for interpreting cross-country differences in $PM_{2.5}$ exposure beyond environmental policy stringency alone.

3.4. Limitations

Several limitations should be acknowledged. First, standardized Environmental Policy Stringency (EPS) data are not available for South Africa and Kenya, limiting direct quantitative comparisons with OECD countries. Consequently, the policy contexts of the African case studies were interpreted using qualitative evidence from published literature and regional environmental governance reports rather than directly comparable EPS indicators.

Second, $PM_{2.5}$ concentrations can be influenced by local factors such as meteorological conditions, geography, and informal activities, including waste burning, which are not captured by the EPS indicator. Third, the time frame of the analysis (2010–2020) may not fully capture the long-term effects of environmental policy, as policy impacts often materialize gradually over extended periods. Despite these constraints, the use of standardized international datasets and comparative analysis provides valuable insights into the relationship between policy stringency and air quality across different regional contexts.

An additional limitation relates to differences in national industrial structures and global production networks. Lower domestic $PM_{2.5}$ levels in some high-income countries may partly reflect the relocation of pollution-intensive industries to other regions through international trade rather than reductions achieved exclusively through domestic environmental policies. Consequently, improvements in local air quality should be interpreted alongside broader patterns of industrial restructuring, consumption, and transboundary environmental impacts. Future research could incorporate consumption-based emissions or pollution footprint indicators to better distinguish between domestic environmental improvements and the displacement of pollution across countries.

4. Results and Discussion

Table 2 presents the main findings by comparing Environmental Policy Stringency scores for Germany and France with average population-weighted $PM_{2.5}$ exposure levels across four countries, Germany, France, South Africa, and Kenya, for the year 2020.

Table 2. EPS scores for the countries selected in this study, data for 2020.

Country	EPS Policy Stringency	$PM_{2.5}$ Exposure (μg/m^3)
Germany	≈5.5	10
France	≈5.1	10
South Africa	N/A	24
Kenya	N/A	24

4.1. General Patterns

Table 2 reveals two primary patterns. First, the European countries in the sample, Germany and France, exhibit the highest Environmental Policy Stringency (EPS) scores and the lowest levels of $PM_{2.5}$ exposure. Second, the African countries, South Africa and Kenya, do not appear in the OECD EPS dataset but display substantially higher levels of $PM_{2.5}$ exposure. This contrast suggests a potential association between policy stringency and improved air quality outcomes, while also highlighting the role of broader structural factors such as governance capacity, economic development, and energy systems.

Germany records an EPS score of approximately 5.5, among the highest in the OECD. This reflects a long-standing commitment to environmental regulation, including renewable energy support mechanisms, vehicle emission standards, and participation in regional climate policy frameworks. In 2020, Germany's $PM_{2.5}$ exposure was approximately 10 μg/m^3 in 2020, representing relatively low pollution levels compared with global averages.

France similarly demonstrates a high level of environmental policy stringency, with an EPS score of approximately 5.1. Its $PM_{2.5}$ exposure level in 2020 was approximately 10 μg/m^3. France's relatively strong air quality outcomes reflect a combination of factors, including nuclear-based electricity generation, participation in European climate policy frameworks, and strict environmental regulations.

In contrast, South Africa and Kenya experience substantially higher $PM_{2.5}$ exposure levels, estimated at approximately 24 μg/m^3 in 2020, more than double the levels observed in the European cases and well above WHO guideline values. Although these countries are not included in the OECD EPS dataset, the comparison illustrates the substantial differences in air quality outcomes across regions with different policies and institutional environments.

The findings indicate that South Africa's higher $PM_{2.5}$ exposure is consistent with its continued dependence on coal-based electricity generation and documented enforcement challenges reported in previous studies. Likewise, Kenya's elevated pollution levels despite its renewable electricity mix suggest that transport emissions, biomass combustion, and waste burning remain significant contributors to ambient particulate matter [17]. This reliance contributes to elevated levels of $PM_{2.5}$ and PM_{10} pollution. Although regulatory frameworks such as the National Environmental Management: Air Quality Act exist, enforcement challenges and economic pressures often constrain their effectiveness. Kenya, by contrast, is less industrialized and generates a significant share of electricity from renewable sources, particularly geothermal energy [35]. Nevertheless, urban air pollution remains a persistent challenge due to rapid motorization, biomass use for household cooking, and open waste burning. While Kenya has adopted climate and environmental policies, limited monitoring infrastructure and institutional capacity continue to impede effective policy implementation.

The comparison of two European cases (Germany and France) with two African cases (South Africa and Kenya) enables the study to explicitly account for contextual differences in the effectiveness of environmental policy. In many European countries, air quality standards and regulatory frameworks are supported by strong institutional capacity, stable financial resources, and consistent enforcement mechanisms, allowing environmental policies to produce measurable improvements in air quality outcomes [36]. In contrast, several African countries face structural and economic constraints that complicate policy implementation. Even where political commitment exists, limitations in institutional capacity, infrastructure, and financial resources can delay or weaken the realization of air quality improvements [37]. This does not render environmental policies ineffective; rather, it highlights the need for complementary measures, including stronger enforcement mechanisms, investment in monitoring infrastructure, and enhanced international cooperation.

4.2. Regional Comparisons

The European cases demonstrate how long-term environmental governance frameworks can contribute to improved air quality outcomes. Germany's Energiewende energy transition strategy has accelerated the expansion of renewable energy, while stringent vehicle emission standards and EU-level climate policies have reduced emissions from transportation and industry. France has similarly benefited from a combination of nuclear energy, environmental regulation, and participation in European carbon pricing mechanisms such as the EU Emissions Trading System. Importantly, these policies operate within strong institutional frameworks supported by robust monitoring systems and regulatory enforcement.

In contrast, the African cases illustrate the challenges of implementing environmental policy within more constrained economic and institutional contexts. South Africa's high $PM_{2.5}$ exposure is largely attributable to its reliance on coal for electricity generation. Although environmental legislation, such as the National Environmental Management: Air Quality Act, exists, enforcement capacity remains limited, and industrial emissions remain significant. Kenya presents a different case: while the country's electricity sector relies heavily on renewable energy, urban air pollution remains elevated due to transport emissions, household biomass use, and open waste burning. These findings suggest that energy transitions alone may be insufficient to improve air quality when other pollution sources remain inadequately regulated.

4.3. Temporal Dynamics

Temporal data provides additional insight into the relationship between environmental policy and air quality outcomes. Between 2010 and 2020, Germany and France experienced gradual increases in EPS scores alongside reductions in $PM_{2.5}$ exposure. Germany's $PM_{2.5}$ exposure declined by more than 15% over this period, while France recorded moderate but consistent improvements, particularly in major urban areas.

In contrast, $PM_{2.5}$ exposure in South Africa remained persistently high throughout the same period, reflecting the continued dominance of coal-based electricity generation and limited enforcement of emissions standards. Kenya similarly exhibited relatively stable $PM_{2.5}$ levels over time, with increases in urban transport activity and population growth offsetting improvements in the electricity sector.

These patterns suggest that environmental policies may require extended time horizons before measurable improvements in air quality become evident. Countries with consistent regulatory frameworks and effective enforcement tend to experience gradual improvements, whereas countries facing institutional or economic constraints may see limited progress despite policy adoption.

4.4. Policy-Outcome Relationship

The observed differences in $PM_{2.5}$ exposure also have important public health implications. Fine particulate matter is a well-established risk factor for cardiovascular disease, stroke, chronic respiratory diseases, lung cancer, and premature mortality. Consequently, the comparatively lower $PM_{2.5}$ exposure observed in Germany and France is expected to be associated with lower air pollution-related health burdens than in South Africa and Kenya, where substantially higher exposure levels increase population health risks. These findings reinforce that environmental policy stringency extends beyond improving environmental quality by contributing to better public health outcomes and advancing sustainable development goals. Although this study does not directly quantify health outcomes such as premature mortality or disability-adjusted life years (DALYs), the established relationship between long-term $PM_{2.5}$ exposure and adverse health outcomes provides an important public health context for interpreting the observed differences in air quality across the selected countries.

The results support the proposition that stronger environmental policy frameworks are associated with improved air quality outcomes (**Table 3**). The European cases demonstrate that high levels of policy stringency can coincide with relatively low $PM_{2.5}$ exposure levels. However, the findings also indicate that policy stringency alone cannot fully explain differences in air quality across countries.

Table 3. Policy stringency and air quality outcomes across study countries.

Country	EPS	$PM_{2.5}$	Institutional Strength	Dominant Energy Structure
Germany	High	Low	Strong	Renewable transition
France	High	Low	Strong	Nuclear + renewables
South Africa	N/A	High	Moderate	Coal dependent
Kenya	N/A	High	Limited	Renewable electricity

Structural factors, including energy system composition, economic dependence on fossil fuels, enforcement capacity, and household energy practices, also play a significant role in shaping pollution outcomes. For example, Kenya's relatively clean electricity mix has not translated into low $PM_{2.5}$ exposure because other major pollution sources, such as transport emissions and household biomass burning, remain prevalent [38]. These results highlight the importance of comprehensive policy frameworks that address multiple pollution sources simultaneously.

4.5. Interpretation of Findings

Given the descriptive and comparative design of this study, these findings should be interpreted as evidence of association rather than causal relationships. The observed patterns likely reflect the combined influence of environmental policies, institutional capacity, energy systems, and other contextual factors. The experiences of Germany and France illustrate how comprehensive environmental policies, implemented within strong institutional and regulatory frameworks, are accompanied by comparatively low levels of particulate matter. This finding is consistent with the broader environmental economics literature, which suggests that policy effectiveness depends not only on regulatory ambition but also on institutional quality and implementation capacity.

However, the comparative analysis also demonstrates that environmental policy stringency alone does not fully explain differences in air quality across countries. The contrasting experiences of South Africa and Kenya indicate that the effectiveness of environmental policies is strongly influenced by contextual factors, including institutional capacity, energy system characteristics, economic structure, and regulatory enforcement. In South Africa, continued dependence on coal-based electricity and implementation challenges constrain progress despite the existence of environmental legislation, whereas Kenya illustrates that relatively clean electricity generation does not necessarily translate into low $PM_{2.5}$ exposure when transport emissions, biomass combustion, and open waste burning remain significant pollution sources. These findings reinforce the importance of considering national circumstances when evaluating environmental policy effectiveness.

The comparative perspective further suggests that policy transfer should be approached cautiously. Rather than assuming that policy models can be replicated directly across regions, the findings indicate that successful environmental governance depends on adapting regulatory approaches to local institutional, economic, and social conditions. While the European experience highlights the benefits of sustained regulatory commitment, long-term investment, and effective enforcement, the African case studies demonstrate the importance of strengthening institutional capacity, expanding monitoring systems, and addressing locally dominant sources of pollution. Consequently, the principal lesson emerging from this comparative analysis is that environmental policy stringency is most effective when integrated with broader governance capacities and context-specific implementation strategies.

4.6. Broader Lessons

Several broader insights emerge from this analysis. First, policy ambition alone is insufficient to achieve meaningful environmental improvements. Countries may adopt comprehensive environmental regulations, but without effective enforcement and institutional capacity, the impact of these policies may remain limited. Second, effective air quality management requires addressing multiple pollution sources simultaneously. For example, Kenya's relatively clean electricity sector has not eliminated air pollution because emissions from transportation, household energy use, and waste burning remain significant. Third, environmental progress requires long-term policy consistency. Improvements in air quality often emerge gradually over decades of sustained policy implementation, regulatory enforcement, and technological transition.

4.7. Policy Recommendations

Based on the findings, several policy recommendations emerge for countries seeking to improve air quality outcomes:

1. Strengthen regulatory enforcement and monitoring systems: Environmental policies must be supported by effective enforcement mechanisms and reliable monitoring infrastructure. Expanding air quality monitoring networks, including ground-based stations and satellite data, can improve transparency and accountability.
2. Promote energy transitions toward cleaner sources: Reducing dependence on fossil fuels, particularly coal, is essential for improving air quality. Investments in renewable energy sources such as solar, wind, and geothermal energy can simultaneously reduce emissions and support long-term energy security.
3. Enhance institutional capacity through international cooperation: Many developing countries face resource constraints that limit environmental policy implementation. International partnerships involving donor institutions, multilateral organizations, and technological cooperation can support capacity building and strengthen environmental governance.

These measures highlight the importance of combining domestic policy reforms with international support to improve air quality outcomes.

4.8. Directions for Future Research

Future research could extend this analysis in several ways. First, expanding the sample to include additional countries from both developed and developing regions would enable broader cross-regional comparisons and improve the generalizability of the findings. Second, future studies could examine additional air pollutants, including nitrogen dioxide (NO_2), ozone (O_3), and particulate matter (PM_{10}), to provide a more comprehensive assessment of environmental policy effectiveness. Third, longitudinal analyses covering longer time periods would help capture the delayed impacts of environmental policies and technological transitions on air quality. Fourth, future research should incorporate quantitative indicators of public health, such as air pollution-attributable mortality, disability-adjusted life years (DALYs), or disease burden, to better evaluate the health benefits associated with improvements in air quality. Finally, future studies could adopt consumption-based environmental indicators and pollution footprint measures to distinguish domestic improvements in air quality from the potential relocation of pollution-intensive production through international trade, thereby providing a more comprehensive assessment of environmental sustainability in an increasingly interconnected global economy.

5. Conclusions

This study examined the relationship between Environmental Policy Stringency (EPS) and air quality through a comparative analysis of Germany and France in Europe and South Africa and Kenya in Africa. By integrating the OECD Environmental Policy Stringency Index with $PM_{2.5}$ exposure data, the study explored how differences in environmental governance, institutional capacity, and energy systems are associated with air quality outcomes across contrasting regional contexts. The comparative approach provided insights into the contextual factors that influence the effectiveness of environmental policies in promoting cleaner air and supporting sustainable development.

The findings indicate that higher environmental policy stringency is generally associated with lower $PM_{2.5}$ exposure, particularly in countries characterized by strong institutions, effective regulatory enforcement, and diversified energy systems. Germany and France exhibited both high EPS scores and relatively low $PM_{2.5}$ exposure, whereas South Africa and Kenya experienced substantially higher particulate matter concentrations under different institutional, economic, and energy conditions. These results indicate that countries with more stringent environmental policy frameworks generally exhibit more favorable air quality outcomes. However, the descriptive nature of the analysis does not permit causal inference, and the observed differences should be interpreted alongside broader institutional, economic, and energy-system characteristics.

Beyond improving environmental quality, the findings also highlight the important public health implications of effective environmental governance. Lower $PM_{2.5}$ exposure is associated with reduced risks of cardiovascular and respiratory diseases, premature mortality, and other adverse health outcomes, emphasizing the close relationship between environmental policy, human health, and sustainable development. However, improvements in domestic air quality should not be interpreted solely as evidence of a reduced global environmental burden. In some cases, lower national pollution levels may also reflect long-term industrial restructuring and the relocation of pollution-intensive production through international trade. Consequently, evaluating environmental sustainability requires consideration of both production- and consumption-based perspectives, together with the international distribution of pollution associated with global supply chains.

This study demonstrates that environmental policy stringency is an important component of achieving cleaner air and improving public health; however, policy ambition alone is insufficient. Effective environmental governance requires strong institutions, consistent regulatory implementation, and consideration of national economic and energy contexts. By highlighting the interplay between environmental policy, governance, air quality, and health across European and African settings, this study contributes to a more nuanced understanding of the conditions under which environmental policies can most effectively support sustainable development.

Author Contributions

A.A. and R.I. contributed to the conceptualization, writing, and revision of the manuscript and approved the final version. Both authors have read and agreed to the published version of the manuscript.

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