Impact of plastic pollution on ecosystem dynamics and greenhouse gas emissions: Empirical evidence and policy implications

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Abstract

The present study undertakes an evaluation of the magnitude of plastic pollution and analyses its repercussions on aquatic, terrestrial, and atmospheric ecosystems, with a specific emphasis on the CO_2 emissions that are a consequence of this pollution. The empirical analysis focuses on a sample of twenty Asian and OECD countries in order to compare the dynamics of plastic production, consumption, and management during 2000-2023.

The findings indicate the presence of significant disparities between the two regions. The Asian economies are distinguished by a pervasive presence of plastic pollution, a phenomenon that is intricately intertwined with the pursuit of rapid economic growth and the dearth of comprehensive waste management systems. In contrast, OECD countries benefit from more structured environmental policies, yet continue to exhibit notably elevated levels of consumption. The analysis also reveals a significant correlation between plastic pollution and carbon dioxide emissions, illustrating the contribution of this pollution to the worsening of climate change. The findings emphasize the necessity for the implementation of integrated public policies that encompass a multifaceted approach to address the environmental and socio-economic challenges posed by plastic.

Keywords: climate change, plastic pollution, GHG emissions, Asian and OECD countries, system GMM.

JEL classification: P52, Q53, Q54, Q57

First submission: 27th November 2025, accepted 7th April 2026

1. Introduction

Plastic pollution has emerged as a significant environmental concern on a global scale. The increasing prevalence of microplastics across diverse ecosystems – including terrestrial, atmospheric, freshwater, and marine environments – reflects the combined effects of population growth, rapid urbanization, and the exponential expansion of plastic production. Once released into the environment, these particles undergo transport through atmospheric, hydrological, and biological pathways, resulting in

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Economics and policy of energy and the environment (ISSNe 2280-7667), 2026, 1
DOI: 10.3280/epe2026oa22888

habitat degradation, disruption of ecological processes, contamination of food webs, and significant threats to the survival of numerous plant and animal species.

Recent research increasingly positions plastic pollution as a critical structural driver of terrestrial ecosystem change. The accumulation of microplastics in soils has been demonstrated to effect alterations to key physicochemical and biological properties, including aggregate stability, porosity, water retention, and nutrient availability. These modifications have the potential to disrupt primary productivity and vegetation dynamics, thereby revealing indirect pathways through which plastic pollution shapes ecosystem functioning and resilience (De Souza Machado et al., 2018; Qi et al., 2018).

Furthermore, microplastics are increasingly recognized not only as pollutants but also as active agents with the capacity to reshape soil ecosystem structure and function. The presence of these substances has been demonstrated to induce alterations in the composition, diversity, and metabolic activity of microbial communities and soil fauna. This, in turn, has been demonstrated to disrupt fundamental biogeochemical cycles, including carbon and nitrogen turnover. From a theoretical standpoint, microplastics have been highlighted as mediators of indirect ecological effects. The interactions of microplastics with biological and physicochemical soil components propagate systemic changes that compromise ecosystem functionality, resilience, and service provision under combined anthropogenic and climatic pressures (Rillig et al., 2019).

The ingestion and accumulation of microplastics by soil organisms establishes a mechanistic pathway that links particle contamination to trophic and structural alterations. The process has been demonstrated to influence a variety of factors, including organismal behavior, physiological performance, and species interactions. The resultant effect of these changes is the intensification of soil structure degradation, which in turn triggers cascading ecological consequences (Huerta Lwanga et al., 2016). Conceptually, these findings advance a framework in which microplastics are not passive contaminants but dynamic disruptors capable of reshaping terrestrial ecosystem processes at multiple scales.

In the context of marine ecosystems, microplastics are increasingly recognized as a pervasive and systemic stressor that penetrates aquatic food webs, impacting organisms across multiple trophic levels. Mithun et al. (2024) provide empirical evidence that microplastic exposure has a detrimental effect on contaminant bioaccumulation and elicits direct toxic effects, including oxidative stress, reproductive impairments, and neurotoxicity in both invertebrates and fish. From a theoretical standpoint, this lends support to the concept of microplastics as vectors that amplify chemical stressors within ecological networks. Furthermore, recent studies have emphasised the interactive effects of microplastic pollution and climate change, particularly in freshwater systems, where elevated temperatures exacerbate negative outcomes on growth, reproduction, and stress physiology (Teggers et al., 2025). This emphasises the heightened vulnerability of aquatic organisms to multiple, concurrent anthropogenic pressures.

The presence of plastic pollution has expanded beyond terrestrial and aquatic environments, becoming pervasive in the atmosphere as well. In this novel domain, micro- and nanoplastics have emerged as contaminants of concern, with the potential to exert substantial ecological and climatic impacts. These particles are released from a variety of anthropogenic sources, including tire wear, the abrasion of synthetic textiles, and the mechanical fragmentation of plastic waste. This phenomenon facilitates long-range transport via atmospheric circulation (Yang et al., 2024).

From a climate-process perspective, Seifried et al. (2026) propose that atmospheric microplastics may actively participate in aerosol formation and modification, although the precise mechanisms remain under investigation. These particles have the capacity to indirectly modify cloud microphysics and potentially influence precipitation patterns, with cascading effects on regional and global climate systems. Theoretically, this positions atmospheric plastic pollution as a systemic disruptor, linking terrestrial, freshwater, and marine biogeochemical cycles, rather than merely an air quality issue. This underscores the necessity of incorporating microplastic dynamics into ecological models and international environmental policies that target the mitigation of atmospheric contaminants.

The present study is situated within the aforementioned context and is structured around two complementary objectives. Firstly, it provides a comprehensive theoretical analysis of the mechanisms of plastic production and degradation, as well as their effects on terrestrial, aquatic, and atmospheric ecosystems. Secondly, an empirical approach is employed to investigate the interactions between plastic pollution and socio-economic, environmental, and institutional variables across 20 Asian and OECD countries. This methodological framework encompasses a systematic evaluation of the contribution of plastic pollution to greenhouse gas emissions. The analysis covers the period from 2000 to 2023 and is founded upon a Generalized Method of Moments (GMM) model.

This research contributes to the extant body of experimental studies by adopting a more extensive analytical framework that integrates key macroeconomic variables, such as production, trade, and consumption patterns. This approach situates plastic pollution within global economic systems while identifying the structural forces that drive it. Furthermore, it introduces an innovative methodology that enhances analytical rigor and supports cross-scale comparisons.

By emphasizing the interconnected nature of environmental, economic, and social factors, the study provides a solid foundation for future research on the global impacts of plastic pollution. This systemic and interdisciplinary perspective is imperative for the development of effective public policies and sustainable management strategies, particularly given the transboundary nature of the issue.

The subsequent section presents a critical review of the relevant literature, followed by a detailed outline of the methodology and the specification of the econometric model. The empirical results are then presented and analyzed, before a discussion synthesizes the main findings and their implications, leading to the conclusion.

2. Literature review

Plastic pollution is acknowledged as one of the predominant anthropogenic pressures impacting global ecosystems. The presence of microplastics in significant quantities in marine environments is attributable to multiple factors, including the progressive fragmentation of large plastic debris, industrial effluents, and urban runoff. These organisms interact with a wide range of other organisms across different trophic levels, facilitating their incorporation into ecological networks. The ingestion and subsequent accumulation of these substances within biological tissues, along with their role in entanglement phenomena, constitute significant stressors that can impact the physiology, reproductive success, and survival of marine organisms.

In this context, Zahari et al. (2022) make a significant contribution to the expanding body of research that frames microplastics as dynamic agents within coastal sedimentary systems, as opposed to viewing them as passive pollutants. The present study was conducted empirically at two intertidal beach sites in Sabah, Malaysia, with the objective of assessing both the presence and the environmental significance of plastic contamination in coastal sediments. Sediment samples were systematically collected and processed using a density separation technique to isolate microplastics, ensuring methodological robustness and comparability with existing studies. The extracted particles were then subjected to complementary visual and chemical analyses, allowing for a detailed characterization of their abundance, size distribution, and polymer composition.

The results indicate a significant presence of microplastics, predominantly composed of small particles of polypropylene and polyethylene. It is of particular significance that these particles frequently co-occur with metals, providing empirical evidence that lends support to the theoretical assumption that microplastics can act as vectors for contaminant transport. By demonstrating this association in situ, the study not only documents pollution levels in a relatively underexplored region but also strengthens the conceptual understanding of microplastics as mediators of pollutant mobility and bioavailability. Consequently, it provides a substantial contribution to the wider discussion on the ecological risks posed by microplastics in coastal environments.

Building on this line of inquiry, Apete et al. (2024) examine fishing-related plastic debris within a socio-ecological framework that recognizes its environmental, economic, and health implications. Utilizing a meticulous examination of scientific and technical literature, which has been selected according to well-defined criteria, the authors synthesize evidence on the abundance, composition, and impacts of such debris. Their analysis identifies fishing residues, particularly nets, ropes and lines, as significant contributors to plastic pollution in specific marine regions. These materials pose a number of risks, including harm to marine fauna, the transport of contaminants, and negative socio-economic effects on coastal communities. The study also underscores substantial knowledge gaps, particularly with regard to long-term impacts and spatial distribution. This viewpoint is corroborated by Grewal et al. (2024), who demonstrate that these pollution pathways have the capacity to compromise the quality of seafood and to disseminate microplastics throughout the food chain, thereby giving rise to concerns regarding public health.

In their 2025 study, Liu and Li propose a novel conceptualization of aquatic ecosystems as dynamic reservoirs and active sinks of microplastics. This theoretical framework integrates the issue of microplastic contamination within a broader theoretical framework of multiple, interacting anthropogenic stressors. The analysis emphasizes that microplastic pollution cannot be comprehended as a standalone phenomenon; rather, it should be regarded as a component of a cumulative pressure system that encompasses thermal warming and other human-induced disturbances. In this context, it is demonstrated that such combined stressors have the capacity to destabilize both benthic and pelagic communities, to alter biogeochemical cycles and ultimately to reduce the resilience and adaptive capacity of aquatic ecosystems. The scientific contribution of their work lies in advancing an integrative perspective that links microplastic contamination to ecosystem functioning and stability, rather than merely documenting its occurrence. By emphasizing the synergistic effects between pollution and climate-related stressors, the study offers a more comprehensive understanding of ecosystem vulnerability. Furthermore, it identifies regions undergoing rapid urbanization and characterized by inadequate waste management as critical hotspots, thereby offering valuable insights for prioritizing future research and environmental management strategies.

The atmospheric accumulation of microplastics gives rise to significant concerns with regard to air quality and highlights their role as vectors of contamination across sensitive ecosystems. In this emerging research field, Gunthe et al. (2021) adopt an integrative atmospheric chemistry approach to examine microplastic-related aerosol dynamics in the urban environments of Delhi and Chennai. The present study combines in situ measurements of submicron aerosols using an Aerosol Chemical Speciation Monitor with thermodynamic simulations based on the ISORROPIA II model. This methodological approach enables the integration of empirical observations with process-based modeling. Their findings reveal a persistent presence of chloride in aerosols, which enhances hygroscopic growth under ammonia-rich conditions and contributes to the formation and persistence of haze events. Of particular significance is the co-occurrence of reactive chlorine species and plastic-derived particles, which indicates the potential for physicochemical interactions that could lead to alterations in the properties of aerosols. This suggests that microplastics could influence atmospheric processes by extending their residence time and modifying particle reactivity. The present study makes a significant contribution to the advancement of scientific knowledge in this field by offering a mechanistic understanding of the interaction between microplastics and atmospheric constituents. This, in turn, serves to expand current perspectives on the role of microplastics in air pollution and their broader environmental impacts.

Moreover, research conducted in protected and remote ecosystems, including the Mangroves and Sundarbans of Bangladesh and India, has demonstrated the presence of atmospheric microplastics even in the absence of direct urban influence. These observations are consistent with the findings of Sathyamohan et al. (2023), and support a growing theoretical perspective that frames microplastics as highly mobile contaminants capable of long-range atmospheric transport and deposition. This challenges the conventional perspective of plastic pollution as a predominantly local or coastal issue, emphasizing its transboundary nature.

In this context, Ammendolia et al. (2025) extend the analysis by examining the biological implications of atmospheric exposure. The research indicates that aerobic organisms, encompassing birds, pollinating insects, and other air-dependent fauna, are subject to continuous exposure to microplastics via inhalation. This exposure pathway introduces a critical, yet underexplored, dimension of ecological risk, as the persistence and small size of these particles may induce physiological stress and disrupt normal biological functions. Collectively, these studies contribute to a more integrated understanding of atmospheric microplastics, linking their dispersal dynamics to ecological vulnerability and reinforcing their significance within global pollution frameworks.

In the context of terrestrial ecosystems, the MICROSOF project (2024) provides a pioneering contribution by establishing the first national benchmarks for microplastic contamination in French soils. A systematic analysis of 33 soil samples drawn from the French soil quality monitoring network was undertaken, revealing the presence of microplastics in 76% of the sites, with a particularly high prevalence in agriculturally managed soils. By establishing a correlation between the presence of microplastic and its potential ecological and agronomic impacts, including alterations in soil biodiversity, inhibition of plant growth, and reductions in agricultural productivity, the research contributes to a theoretical understanding of soils as active sinks for persistent pollutants. The present study makes a significant contribution to the extant body of knowledge by conceptualizing microplastic pollution not merely as a chemical contaminant, but as a factor with tangible consequences for ecosystem functioning and food security. This framework provides critical data to guide both environmental monitoring and sustainable land management strategies.

In their study, Chen et al. (2025) investigated the interactions between polyethylene microplastics and aged biochar, in order to evaluate their combined effects on soil greenhouse gas dynamics. The research, which was conducted over the course of a 91-day laboratory experiment, has made significant contributions to the theoretical understanding of the ways in which microplastics interfere with biochemical processes in soil and carbon stabilization mechanisms. The findings indicate that the presence of microplastic has a detrimental effect on the efficacy of biochar, resulting in increased greenhouse gas emissions and diminished microbial necromass carbon sequestration. These findings provide support for the hypothesis that plastic pollution constitutes a significant barrier to effective carbon management and sustainable soil practices. The present study makes a significant contribution to the field by emphasizing the necessity of accounting for microplastic contamination in soil amendment strategies. It is imperative that pollution considerations are incorporated into ecosystem management and climate mitigation frameworks.

In their seminal study, Shi et al. (2025) employed controlled microcosm experiments to investigate the influence of microplastics on the bio-accessibility of dissolved organic matter and the dynamics of mineral-associated carbon in soils. The present study employs an experimental approach to investigate the interactions between synthetic particles and soil carbon processes. In order to achieve this objective, microplastics composed of diverse polymer types are subjected to incubation with mineral matrices, and the ensuing results are then compared with those derived from natural organic matter. This methodological approach offers mechanistic insights into the subject. The findings indicate that microplastics have a substantial impact on carbon dioxide (CO_2) emissions, exhibiting a range of 21% to 576% increase, while concurrently diminishing mineral-associated organic carbon by 34% to 83%. The findings demonstrate that microplastic contamination has the potential to destabilize soil carbon stocks and intensify greenhouse gas emissions, thus highlighting an hitherto underappreciated pathway through which plastic pollution can undermine soil ecosystem functioning and contribute to climate change.

Flood-Garibay et al. (2023) present a comprehensive review of the extant literature on the neurological impacts of suspended and ultrafine particles originating from urban plastic pollution. Utilizing a systematic review of epidemiological and experimental studies, the authors assess particle composition, concentration, and sources across diverse urban settings. The analysis demonstrates a correlation between exposure to fine and ultrafine particles and the accumulation of nanoparticles in the brain. This accumulation has been demonstrated to trigger inflammatory and oxidative responses, which may contribute to neurodegenerative diseases such as Alzheimer's and Parkinson's. Of particular significance is the study's finding that chronic exposure to plastic may also result in impaired cognitive function, delayed neurological development, and deterioration in mental health. This development serves to expand the established health risks associated with plastic pollution, extending beyond the respiratory and cardiovascular effects that have previously been documented. This work contributes to the theoretical understanding of environmental neurotoxicology and emphasizes the pressing need to incorporate plastic-derived particles into public health strategies.

This synthesis of the scientific literature underscores the systemic nature and complexity of the dynamics associated with plastic pollution and microplastics, as well as their multiscalar impacts on ecosystems and biogeochemical processes. In this context, the following section endeavors to address the identified knowledge gaps by proposing an integrated empirical framework. The overarching objective of this framework is to elucidate the socio-economic, environmental, and institutional dimensions that underpin plastic pollution. Furthermore, the model has been developed for the purpose of facilitating a quantitative assessment of their contribution to greenhouse gas emissions using advanced econometric models.

3. Model specification, variables definition, and methodological approach

The period from 2000 to 2023 has been characterized by a simultaneous expansion of plastic production, an increasing accumulation of microplastics in natural ecosystems, and a sustained rise in greenhouse gas emissions. The present study focuses on Asian countries and OECD member states, which were selected based on three key criteria. Firstly, it is imperative to acknowledge that these regions collectively contribute to more than 70% of the global greenhouse gas emissions (OECD, 2025). Secondly, the selected countries exhibit substantial heterogeneity in their ecological and socio-economic characteristics, providing a suitable analytical context for investigating the linkages between plastic production, environmental pollution, and greenhouse gas emissions. Thirdly, these countries offer reliable and internationally comparable data for the variables included in the system GMM framework, which is essential to ensure the robustness of the empirical analysis.

3.1. Problematic

This empirical research aims to address two fundamental questions:

- To what extent do socio-economic and institutional factors drive plastic pollution in contrasting regional contexts, specifically between Asian countries and OECD member states?
- How does plastic pollution contribute to the intensification of greenhouse gas emissions?

By addressing these inquiries, the study contributes to a more profound comprehension of the dynamic interactions between plastic pollution, and greenhouse gas emissions, offering insights that can inform targeted and effective policy interventions.

3.2. Model specification

Equation (1) is designed to explain the level of plastic pollution generated ($PP_{i,t}$) based on the selected socio-economic and institutional variables (Table 1). The dynamic model can be formulated as follows:

$$PP_{i,t} = \alpha_0 + \alpha_1 PP_{i,t-1} + \beta_1 AGE15\text{-}64_{i,t} + \beta_2 AGE65^{+}_{i,t} + \beta_3 URB_{i,t} + \beta_4 UPRI_{i,t} + \beta_5 MAN_{i,t} + \beta_6 SER_{i,t} + \beta_7 CC_{i,t} + \beta_8 GDPPCG_{i,t} + \mu_i + \lambda_t + \nu_{i,t} \tag{1}$$

Equation (2) examines the effects of carbon dioxide (CO_2), generated by plastic pollution, on greenhouse gas emissions ($GHG_{i,t}$):

$$GHG_{i,t} = \gamma_0 + \gamma_1 GHS_{i,t-1} + \delta_1 CO_{2i,t} + \delta_2 GDPPCG_{i,t} + \mu_i + \lambda_t + \nu_{i,t} \tag{2}$$

The model incorporates individual fixed effects (μ_i), time effects (λ_t), and an idiosyncratic error term ($\nu_{i,t}$). The selection of explanatory variables is grounded in a thorough review of the recent econometric literature, notably the studies by Pambudi et al. (2025) and Zhang et al. (2021), which are widely recognized as key references in this field. The estimation process employs the system generalized method of moments (System GMM) framework, which was developed by Blundell and Bond (1998) for dynamic panel models. This approach rigorously addresses endogeneity, reverses causality, measurement errors, and omitted variable bias by combining equations in first differences and in levels. It provides estimates that are consistent, efficient, and robust, as emphasized by Baum et al. (2007). The assessment of variable stationarity is conducted through the implementation of panel unit root tests, as proposed by Im et al. (2003). The evaluation of instrument validity is facilitated by the Hansen and Sargan tests. Finally, serial correlation in the residuals is examined via the Arellano-Bond AR(1) and AR(2) tests.

Table 1 – Definition of variables

Variables	Definitions	Sources
	Dependent variables	
$PP_{i,t}$: Plastic pollution	Plastic pollution (PP) is defined as the annual quantity of inadequately managed plastic waste. This includes waste discharged into terrestrial, atmospheric, and aquatic ecosystems, "unaccounted for" waste (for which the treatment category is unspecified), as well as "other" types of waste, i.e., those that do not fall into any of the categories defined by the World Bank. PP is measured in metric tons.	World Bank Group (2023a; 2023b)
$GHS_{i,t}$: Greenhouse gases	These gases are responsible for the trapping of heat within the atmosphere, thereby contributing to the phenomenon of global warming. As a consequence of human activities, there has been an increase in the number of these entities, which has the effect of intensifying this phenomenon and giving rise to climate change (Gallandat *et al.*, 2017).	World Development Indicators (WDI)
	Independent variables	
$AGE15\text{-}64_{i,t}$: Population age group 1	This demographic variable represents the percentage of the population aged 15–64 years. It reflects the active labor force, which is expected to influence both the consumption and production of plastic waste (Yan et al., 2024). The coefficient of this variable is anticipated to have a positive sign.	(WDI)
$AGE65^{+}_{i,t}$: Population age group 2	AGE65^{+} represents the share of the population aged 65 and over in the total population. This demographic group is often associated with distinct consumption patterns and potentially different waste management practices. The coefficient of this variable is expected to be positive.	(WDI)
$URB_{i,t}$: Proportion of urban population in the total population	URB is measured as the percentage of the population residing in urban areas, where higher population density and urban lifestyles often lead to increased plastic waste generation (OECD, 2022; 2024). The expected sign is positive.	(WDI)
$UPRI_{i,t}$: Percentage of the largest city's population in the urban population	The UPRI is defined as the percentage of the urban population in the largest city and is used to describe urbanization patterns. The coefficient of this variable is expected to be positive.	(WDI)
$MAN_{i,t}$: Value-added output of the manufacturing sector ; percentage of GDP	MAN represents the value-added MAN, as percentages of the GDP and is considered as proxy for the contribution of the manufacturing sector to the GDP. The expected sign of its coefficient is positive.	(WDI)
$SER_{i,t}$: Value-added output of the service sector ; percentage of GDP	SER represents the value-added of the service sector as a share of GDP and is used as a proxy for the sector's contribution to the GDP. The expected sign is positive	(WDI)
$GDPPCG_{i,t}$: annual growth rate of GDP per capita at constant 2010 prices.	GDPPCG is a key economic indicator, defined as the change in average per capita wealth generated over a given period (Stern, 2004). The coefficient of this variable is expected to be positive.	(WDI)
$CO_{2i,t}$: Percentage of CO_2 emissions produced by plastic pollution	This variable denotes the greenhouse gases that are produced during the manufacturing, transportation, utilization, and disposal of plastics, with the majority of these gases being derived from fossil fuels (Geyer *et al.*, 2017; Royer *et al.*, 2018). The coefficient of this variable is expected to be positive.	(WDI)
CCi,t : Corruption Control Index	According to the Worldwide Governance Indicators, corruption is defined as the perception of the extent to which public power is exercised for private gain. This definition encompasses both petty and grand forms of corruption, as well as the "capture" of the state by elites and private interests. The coefficient of this variable is expected to be positive.	Worldwide Governance Indicators (WGI)

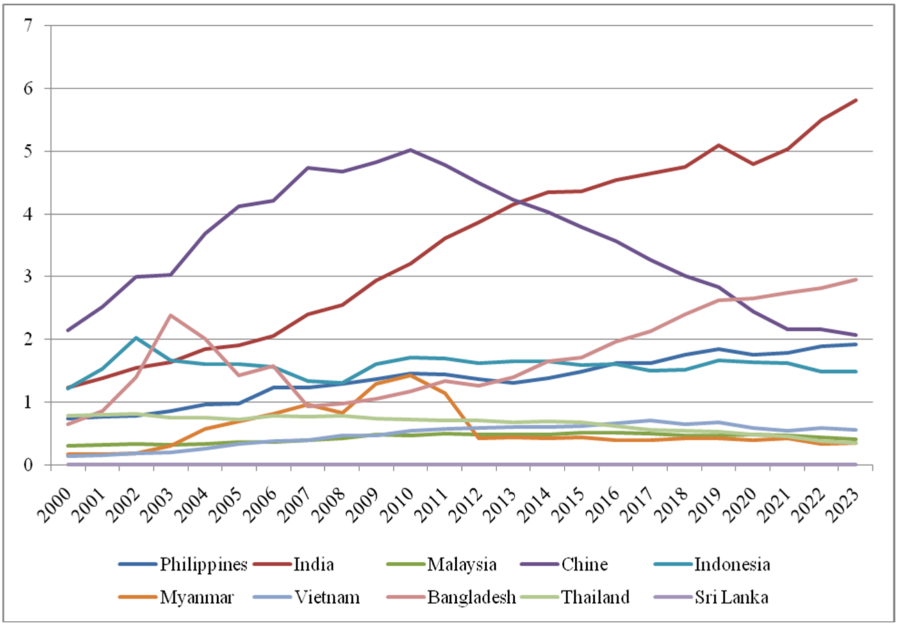
Note: Compiled by the author. The letter pairs employed in this article serve as the symbols used to denote the variables employed.

3.3. Sample description

The sample consists of twenty countries, which have been divided into two distinct groups. The objective of this division is to identify the factors driving plastic pollution and to highlight regional characteristics influencing plastic production and greenhouse gas emissions.

The ten Asian countries examined – Bangladesh, China, India, Indonesia, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, and Vietnam – are distinguished by their substantial populations and, since the 2000s, by accelerated economic growth, urbanization, and sustained industrial development. These changes have led to a significant increase in plastic pollution (see Figure 1), driven by the expansion of manufacturing industries, retail trade, and e-commerce, in a context of still limited environmental policies. China, Indonesia, and the Philippines are among the world's largest contributors to plastic waste, largely due to often insufficient waste management and relatively low recycling rates.

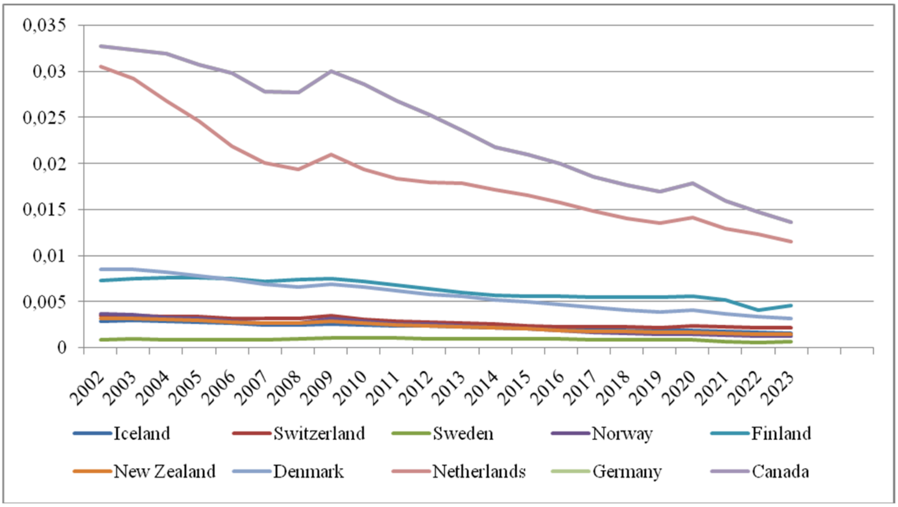
Figure 1 – Evolution of plastic pollution (Asian countries, 2000-2023)



Source: World Development Indicators (2024). Compilation of the author

The ten OECD member countries examined – Canada, Denmark, Finland, Germany, Iceland, New Zealand, Netherlands, Norway, Sweden, and Switzerland – are advanced economies characterized by high income levels, well-developed industrial and logistical infrastructures, and established institutional and environmental frameworks. These countries are distinguished by per capita plastic consumption that significantly exceeds the global average, while benefiting from more structured public policies for the reduction, management, and recycling of plastic waste. These policies are indicative of a commitment to mitigating the environmental impact of these countries (see Figure 2).

Figure 2 – Evolution of plastic pollution (OECD countries, 2000-2023)



Source: World Development Indicators (2024). Compilation of the author.

3.4. Descriptive study of variables

The descriptive analysis of the data collected over the period 2000–2023 allows for the characterization of the main variables considered for the Asian countries and the assessment of their dispersion, a crucial aspect for interpreting the subsequent econometric results. Table 2 presents a summary of the number of observations as well as the mean, standard deviation, minimum, and maximum values for each of the variables studied.

The analysis of the descriptive statistics indicates that the mean value of plastic pollution (PP) is 1.38, with a standard deviation of 1.33. This finding suggests a relatively high dispersion of observations and substantial heterogeneity among the Asian countries. The maximum value of the variable in question reaches 5.817, as observed in India in 2023 (see Figure 1), while the minimum value, which is found to be extremely low at 0.0002, is recorded in Sri Lanka during the same year. The observed variation in these metrics indicates the presence of substantial disparities among nations with respect to their levels of plastic waste generation. These disparities may be indicative of fundamental discrepancies in economic development, industrial dynamics, and environmental management policies.

From a demographic perspective, the active population (AGE15-64) constitutes, on average, 66% of the total population. This suggests a structural propensity that is conducive to economic activity and consumption, and consequently, potentially to plastic waste generation. The maximum value, 72.937%, was observed in China in 2009. This can be attributed to a relatively high active population density and an increased potential for production and consumption. Conversely, the minimum value of 58.533%, recorded in the Philippines in 2000, reflects a smaller active population.

Concurrently, the proportion of the aged population (AGE65^+) remains relatively modest, with a mean of 7%, yet exhibits substantial dispersion, reaching up to 50% in certain instances. This variability is indicative of substantial disparities in the stages of demographic transition across Asian countries. The maximum value of 50.06% was observed in India in 2009, indicating a rising share of the elderly population. Conversely, the minimum value of 3.761% was recorded in Bangladesh in 2000, suggesting a younger demographic structure. These cross-country variations underscore the crucial role of demographic structure in analyzing the determinants of plastic pollution and the pressure on ecosystems.

Urbanization (URB) has an average of approximately 40%, with primacy in the largest city (UPRI) at 20.57%, reflecting contrasting dynamics in population concentration. In 2023, Malaysia attained a high urbanization level of 78.716%, a development that is statistically significant. Such a level of urbanization is commonly associated with increased consumption and higher plastic waste generation. Conversely, the minimum value of 18.196%, documented in Sri Lanka in 2012, signifies a more rural demographic profile. These disparities across the country suggest a potential influence of urbanization on environmental pressures and plastic waste production.

An examination of the UPRI variable reveals a higher degree of urban primacy in Bangladesh (34.153% in 2000), while China exhibits a notably lower value (3.066% in 2000), suggesting a more balanced urban system.

From a structural perspective, the service sector (SER) is the predominant economic activity, with an average share of 48%. The manufacturing sector (MAN) is the second-largest contributor to the economy, accounting for approximately 21% of economic activity. This observation suggests a potential correlation between the level of economic development, goods consumption, and plastic waste generation.

In the year 2000, China was distinguished as a predominant actor in the manufacturing sector, with a 35.008% share, underscoring its significance in the global economy. Conversely, Myanmar demonstrated a notably lower percentage of 7.551% in 2001. With respect to the service sector, the Philippines attained a maximum share of 62.101% in 2023, signifying a predominantly service-oriented economy. Conversely, Myanmar recorded the minimum value of 32.549% in 2000, suggesting a pronounced emphasis on primary and manufacturing sectors. These disparities across the country highlight the hypothesis of a correlation between economic structure and goods production, and, by extension, plastic waste generation.

The average greenhouse gas (GHG) emissions are 1,641 kt CO_2-equivalent, with high dispersion (standard deviation of 3,455), reflecting significant disparities between low-emission countries and those with high industrialization or fossil fuel dependency. In 2023, China's energy consumption reached a peak of 15,943.99 kt, underscoring the magnitude of its industrialization and its reliance on fossil fuels. Conversely, Sri Lanka demonstrated notably diminished consumption in 2001, reaching a nadir of 25,499 kilograms. This decline can be ascribed to prevailing economic conditions that are distinct to the nation.

Carbon dioxide emissions demonstrate a comparable trend, exhibiting an average of 40.35 million tons, a maximum of 437 million tons in China in 2023, and a minimum close to zero in Myanmar in 2009. The data presented herein illustrate markedly divergent energy trajectories, with a concomitant focus on the nexus between plastic production and consumption.

The mean values of the Corruption Control Index (CC) and the GDP per capita growth rate (GDPPCG) are 0.36 and 4.4%, respectively. The (CC) value attained a high level in Malaysia (0.673 in 2013) and a very low level in Myanmar (0.00476 in 2010). A thorough examination of the economic data reveals a conspicuous divergence in GDP per capita growth rates, ranging from 13.636% in China in 2007, a period characterized by substantial economic expansion, to -12.629% in Myanmar in 2021, signifying an acute recession.

The study's findings indicate the presence of substantial structural and institutional disparities, as well as varied economic trajectories among the Asian countries. These observations may have implications for strategies aimed at managing plastic pollution in the region.

Table 2 – Descriptive statistics of variables, Asian countries

Variables	**Obs**	**Mean**	**Std. dev.**	**Min**	**Max**
PP	240	1.379378	1.335661	0.000192	5.817643
AGE15-64	240	0.6652754	0.0344248	0.58533	0.72937
$AGE65^{+}$	240	0.0690708	0.0367907	0.03761	0.5006
URB	240	0.405566	0.1512869	0.18196	0.78716
UPRI	240	0.2057461	0.1087453	0.03066	0.34153
MAN	240	0.2121778	0.0594745	0.07551	0.35008
SER	240	0.4794826	0.0694664	0.32549	0.62101
GDPPCG	240	0.0444786	0.0360025	-0.12629	0.13636
CC	240	0.358737	0.1588681	0.00476	0.67299
GHS	240	1641.149	3455.093	25.4987	15943.99
CO_2	240	40.34644	93.25629	0.2568819	437.5681

Source: Compilation of the author

A thorough statistical analysis of the variables presented in Table 3, concerning OECD member countries, unveils considerable heterogeneity in plastic pollution (PP) emissions. The mean value of these emissions is 0.0092, with a standard deviation of 0.0099. This indicates a relatively moderate average level, but significant variation across countries. The data reveal significant disparities within the OECD, as evidenced by the wide range of values reported, from as low as 0.00065 in Sweden in 2022 to as high as 0.0340 in the Netherlands in 2000 (see Figure 2). Such disparities are indicative of structural discrepancies in environmental pressure, the efficacy of public policies, and the economic mechanisms for managing plastic pollution.

Moreover, the working-age population (AGE15-64) constitutes an average of 65.8% of the total population, with a relatively low standard deviation (0.016). This finding suggests a degree of homogeneity among countries with regard to the demographic structure of this age group. Conversely, the proportion of the population aged 65 and over ($AGE65^{+}$) averages 16.6%, yet demonstrates greater variability (standard deviation = 0.0287). This higher dispersion underscores the presence of structural heterogeneity across countries, thereby suggesting that the demographic aging process manifests differently within the OECD.

The urbanization rate (URB) is high, with an average of 83.4%, confirming the predominance of urban populations in OECD countries. However, the relatively large standard deviation (0.058) underscores substantial heterogeneity among countries, juxtaposing highly urbanized economies with those where the rural component persists in significance. The urban primacy index (UPRI) reveals a mean of 20.435% and a substantial dispersion of 8.44%, indicative of structural diversity in urban systems. This variability mirrors heterogeneous patterns of urban hierarchy and spatial polarization, which can influence territorial dynamics as well as the production and management of environmental externalities, particularly those associated with plastic pollution.

An analysis of the economic structure of OECD countries reveals that the manufacturing sector (MAN) contributes relatively modestly to GDP, with an average of 13.4% and a standard deviation of 4.33%. This finding suggests the presence of significant cross-country variations in the degree to which industrial activity is relied upon, reflecting the broader processes of relative deindustrialization and sectoral restructuring that are characteristic of advanced economies. Conversely, the service sector (SER) has emerged as the predominant sector, accounting for an average of 62.9% of the total employment, thereby underscoring the ongoing process of tertiarization and the transition toward a post-industrial, service-oriented economic model.

Furthermore, the Corruption Control Index (CC) demonstrates a high mean value of 0.9706 with minimal variability (standard deviation = 2.17), indicating substantial institutional homogeneity across OECD countries. This phenomenon aligns with the consolidation of governance frameworks and the overall high institutional quality that characterizes these advanced economies.

The average annual GDP per capita growth in OECD countries has remained relatively modest, with a mean of 1.1% and a standard deviation of 2.39%. The presence of extreme fluctuations – ranging from a contraction of -8.5% in Finland in 2009 to an expansion of 6.8% in Iceland in 2004 – highlights the vulnerability of advanced economies to cyclical fluctuations and macroeconomic shocks. Furthermore, economic growth may directly impact plastic pollution emissions, particularly through increased production activity, heightened consumption of plastic-intensive goods, and shifts in urban and industrial lifestyles.

The mean value of total greenhouse gas emissions is 225 units, with a standard deviation of 310, suggesting significant cross-country dispersion. While certain countries have reported relatively low emission levels – for example, Iceland in 2000 (391 units) – others have exhibited exceptionally high emissions, notably Germany in 2001 (1,043.99 units). This pronounced heterogeneity underscores the uneven contribution of countries to atmospheric pollution and reflects structural differences related to levels of economic development and energy mix composition.

With regard to carbon dioxide (CO_2) emissions in particular, disparities are even more pronounced. The minimum observed value (0.094 units in Iceland in 2000) indicates that some countries generate virtually negligible emissions, whereas the maximum value (2.11 × 109 units in Germany in 2022) illustrates the magnitude of emissions in large industrialized economies. These disparities imply that carbon dioxide (CO2) exerts a pivotal influence on the variances in atmospheric contamination across OECD nations. Indeed, highly industrialized and fast-growing economies tend to exhibit higher levels of pollution, while service-oriented economies with cleaner energy mixes record comparatively lower emissions.

Table 3 – Descriptive statistics of variables, OECD countries

Variables	Obs	Mean	Std. dev.	Min	Max
PP	240	0.0092551	0.0099158	0.000652	0.034005
AGE15-64	240	0.6587632	0.0164447	0.61469	0.69524
$AGE65^{+}$	240	0.166409	0.0287596	0.11549	0.23618
URB	240	0.8348529	0.0581289	0.73375	0.94042
UPRI	240	0.2043548	0.0844158	0.05413	0.37909
MAN	240	0.1346716	0.0433547	0.05171	0.2415
SER	240	0.6299656	0.0561873	0.39633	0.72869
CC	240	0.9706144	0.0217406	0.91827	1
GDPPCG	240	0.0112869	0.0239051	-0.08513	0.0686
GHS	240	225.0088	310.0339	3.912	1043.991
CO2	240	9221361	1.36e+08	0.0941853	2.11e+09

Source: Compilation of the author

4. Results

Tables 4 and 5 present the empirical results derived from Equations (1) and (2). The Hansen and Sargan tests, which evaluate the validity of the instruments, in conjunction with the Arellano-Bond AR(1) and AR(2) tests for serial correlation in the residuals, substantiate the robustness and statistical validity of the selected dynamic model.

For both groups under study, the coefficients of the lagged variable (PP_{t-1}) are positive and statistically significant, revealing a strong inertia effect in plastic pollution. This finding suggests that past levels of plastic pollution have a significant impact on current outcomes, particularly in OECD countries, where waste persistence reflects historically intensive patterns of consumption and production. These results underscore the importance of structural interventions, such as policies aimed at reducing plastic use and the adoption of green technologies, to disrupt this dynamic and promote a more sustainable environmental trajectory (Senate Report, 2020; Barnes, 2019).

The demographic variables AGE15-64 and AGE65$^+$ demonstrate statistically significant effects on plastic pollution in OECD member countries. Specifically, the empirical results indicate that AGE15-64 has a positive effect, whereas AGE65$^+$ exerts a negative impact. The working-age population is more actively engaged in socio-economic activities and tends to adopt lifestyles associated with higher levels of plastic consumption, which explains the observed positive effect (Liddle, 2011).

Conversely, the adverse effects associated with the elderly population can be ascribed to reduced consumption patterns involving fewer plastic products and heightened engagement in pro-environmental behaviors, such as waste reduction and recycling (Gifford and Nilsson, 2014; Hartley et al., 2018). Consequently, an increased proportion of older individuals within a population tends to mitigate plastic pollution, underscoring the pivotal role of consumption choices and environmentally responsible behaviors in shaping pollution dynamics.

The coefficient of the urbanization variable (URB) is significantly negative; suggesting that poorly managed urbanization in certain Asian countries is associated with intensified environmental pressures. These findings are consistent with earlier studies showing that urbanization can deteriorate environmental quality and support the ecological modernization theory, which argues that societies tend to prioritize economic development over environmental quality at early stages of development (Poumanyvong and Kaneko, 2010; Zhu et al., 2022).

Conversely, in OECD countries, the URB variable demonstrates a negative yet less pronounced effect. Despite the considerable degree of urban concentration present, this region is distinguished by the presence of highly effective waste management systems and a rigorous environmental policy framework. This result aligns with the findings of Martínez-Zarzoso and Maruotti (2011) and more recent analyses by Chen et al. (2021), which suggest that urbanization in developed countries, may lead to the stabilization or even reduction of emissions through scale effects and technological innovation.

The findings suggest that the manufacturing sector (MAN) exerts a positive and statistically significant effect on plastic pollution in both groups of countries. This phenomenon is particularly evident in Asian countries, where a 1% increase in the manufacturing sector is associated with an approximate 11% rise in plastic pollution (see Table 4). The utilization of plastic-intensive inputs is pervasive across various manufacturing sectors, thereby exacerbating plastic pollution. This finding lends further credence to the argument that industrialization continues to be a primary driver of plastic pollution in Asian countries.

These results align with the findings of Cole and Elliott (2003) and Jirapornvaree et al. (2023), who demonstrate that the substantial reliance of developing countries on manufacturing activities tends to augment greenhouse gas emissions and environmental contamination. In OECD member countries, the impact of the manufacturing sector remains statistically significant, albeit to a comparatively lesser extent. This discrepancy can be attributed to the processes of relative deindustrialization and the gradual tertiarization of these economies.

However, the findings of the study suggest that the service sector may not be as environmentally neutral as previously assumed. In Asian countries, the service sector variable (SER) demonstrates a positive and statistically significant coefficient. A 1% increase in SER has been shown to result in an approximate 8% rise in plastic pollution, as illustrated in Table 4. Conversely, within the context of OECD member countries, the impact of the service sector appears to be statistically insignificant (Table 3).

The service sector, a broad category encompassing a wide range of activities, is a significant contributor to environmental degradation. On one end of the spectrum, there are activities with low environmental impact, such as banking and consultancy. On the other end of the spectrum are activities that generate substantial amounts of plastic waste, such as food services and tourism. Consequently, these opposing forces may counterbalance each other, resulting in an overall negligible effect on SER. This outcome can be attributed to the implementation of more stringent recycling and waste reduction policies, which mitigate the environmental impact of service sector growth in OECD countries (OECD, 2022).

The coefficient associated with the institutional variable (CC) is found to be negative and statistically significant for the OECD country sample (Table 4), indicating that institutional quality is a key determinant of plastic pollution. These results align with extant theoretical and empirical evidence, including the findings of Leitão (2010) and Cordier et al. (2021). As demonstrated in the research by Sulemana et al. (2017), higher levels of corruption have been shown to have a deleterious effect on public intervention in environmental quality issues and the effective implementation of environmental regulations.

The impact of economic growth on plastic pollution is not uniform across countries, exhibiting divergent effects that are contingent on the developmental levels of the respective nations. In the context of Asian economies, the coefficient associated with GDP per capita growth (GDPPCG) is found to be positive and statistically significant (see Table 4). This finding aligns with the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental degradation initially rises as income grows. This phenomenon can be attributed to the lower priority assigned to environmental quality in many Asian countries, as well as the relocation of pollution-intensive industries from developed to developing economies (Roca et al., 2001; Sulemana et al., 2019).

In contrast, a negative relationship between economic development and environmental pressure is observed in OECD countries. Specifically, a 1% increase in GDP per capita has been shown to result in a 3.21% reduction in plastic pollution, as illustrated in Table 4. This relationship is indicative of a context in which, beyond a certain income threshold, technological innovation and stricter environmental policies have been shown to mitigate – or even reverse – the adverse environmental effects of economic growth (Liddle and Messinis, 2015; Yan et al., 2024).

The present study demonstrates a statistically significant correlation between plastic pollution and greenhouse gas (GHG) emissions across both groups of countries analyzed (Equation 2). This finding signifies a substantial contribution to the field of research. In Asian economies, the CO2 variable demonstrates a positive and statistically significant coefficient (see Table 5), indicating that CO_2 emissions associated with plastic pollution contribute substantially to overall greenhouse gas (GHG) emissions. Additionally, research has demonstrated a robust correlation between economic growth, as quantified by GDP per capita (GDPPCG), and greenhouse gas emissions. This dynamic underscores the pivotal role of productive activities and increased consumption in driving the flow of these emissions.

In OECD countries, the effect of the CO_2 variable remains positive and statistically significant, although its magnitude is considerably lower than that observed in Asian economies. This discrepancy indicates that institutional frameworks, environmental policies, and technological advancements implemented in these countries contribute to mitigating the impact of plastic pollution on greenhouse gas emissions. However, it is crucial to acknowledge the persistent influence of economic growth on this phenomenon, suggesting that the relationship between economic development and environmental pressures remains only partially decoupled, despite advances in regulation and technology. These findings are consistent with projections by Lau et al. (2020), which identify the Asian region as the primary global hotspot for mismanaged plastic waste and atmospheric pollution. Furthermore, the empirical results support the conclusions of previous studies by Geyer et al. (2017), underscoring the inadequacy of global plastic recycling initiatives. This observation underscores the long-term environmental consequences, particularly regarding greenhouse gas emissions.

In summary, the present study underscores the notion that plastic pollution is the result of intricate interactions among socio-economic, environmental, and institutional factors, thereby reflecting its structural rather than cyclical nature. The empirical evidence indicates that plastic pollution exerts a considerable influence on greenhouse gas emissions, particularly carbon dioxide (CO_2), in both Asian economies and OECD countries. This relationship underscores the notion that plastic pollution is not merely a waste management issue but is intrinsically linked to the broader context of climate change.

Table 4 – Estimation of equation (1), PP: dependent variable

	Coefficients	**Std_error**	**Z**	**P>Z**	**Coefficients**	**Std_error**	**Z**	**P>Z**
	Asian countries				**OECD countries**			
PP_{t-1}	0.83786*	0.09664	8.67	0.000	1.53818*	0.28569	5.38	0.000
AGE15-64	-	-	-	-	0.20738**	0.09875	-2.10	0.036
$AGE65^{+}$	-	-	-	-	-0.06236**	0.02879	-2.17	0.030
URB	-1.76514**	0.76812	-2.30	0.022	-0.00587***	0.00333	-1.76	0.078
UPRI	-25.88612**	12.2984	-2.10	0.035	0.02912**	0.01464	1.99	0.047
MAN	10.8097**	5.00804	2.16	0.031	0.0089*	0.00308	2.89	0.004
SER	7.97183**	3.75021	2.13	0.034	0.0059	0.00399	1.48	0.138
GDPPCG	0.58569**	0.77988	0.75	0.0453	-0.03209*	0.01140	-2.81	0.005
CC	-	-	-	-	-0.03909**	0.01986	-1.97	0.049
_cons	0.14136	0.14503	0.97	0.330	0.09804**	0.04549	2.16	0.031
AR(1)	z = -1.01 Pr > z = 0.314				z = -1.79 Pr > z = 0.074			
AR(2)	z = -0.60 Pr > z = 0.550				z = -1.80 Pr > z = 0.272			
Test de Sargan	chi2(22) = 42.37 Prob > chi2 = 0.206				chi2(22) = 65.17 Prob > chi2 = 0.364			
Test de Hansen	chi2(22) = 0.64 Prob > chi2 = 1.000				chi2(22) = 0.00 Prob > chi2 = 1.000			

Source: Compilation by the author. *: $p < 0.01$; **: $p < 0.05$ and ***: $p < 0.1$

Table 5 – Estimate of equation (2), GHG: dependent variable

	Coefficients	**Std_error**	**Z**	**P>Z**	**Coefficients**	**Std_error**	**Z**	**P>Z**
	Asian countries				**OECD countries**			
GHS L1.	0.4141126*	0.15024	2.76	0.006	0.9619614*	0.01007	95.53	0.000
CO_2	21.58581*	5.18963	4.16	0.000	1.52e-08*	4.59e-09	3.31	0.001
GDPPCG	7140.754*	308.8405	23.12	0.000	587.0533*	176.2977	3.33	0.001
_cons	-221.6853*	32.1916	-6.89	0.000	-5.031347	4.30868	-1.17	0.243
AR(1)	z = -2.62 Pr > z = 0.129				z = -1.60 Pr > z = 0.110			
AR(2)	z = -1.20 Pr > z = 0.231				z = -2.07 Pr > z = 0.438			
Test de Sargan	chi2(22) = 0.44 Prob > chi2 = 0.801				chi2(2) = 4.90 Prob > chi2 = 0.186			
Test de Hansen	chi2(22) = 2.42 Prob > chi2 = 0.298				chi2(2) = 1.97 Prob > chi2 = 0.374			

Source: Compilation by the author. *: $p < 0.01$; **: $p < 0.05$ and ***: $p < 0.1$

5. Discussion

The results obtained from the system GMM model employed in this study have allowed the identification of key variables that can guide effective strategies for preventing future plastic pollution and reducing the externalities associated with greenhouse gas emissions. From this perspective, four policy implications emerge. Initially, South Asian countries and China are identified as priority targets, as they are projected to become the primary contributors to global plastic pollution, accounting for approximately 35% of the global total by 2050 – more than one-third of worldwide plastic pollution (OECD, 2025). Conversely, plastic pollutant emissions from OECD countries are projected to be nearly negligible by 2050 (Ministry of the Environment Japan, 2021). Consequently, these countries are called upon to intensify their efforts to reduce accumulated plastic waste before it degrades into microplastics, the removal of which proves particularly challenging.

Secondly, demographic shifts are anticipated to exacerbate plastic pollution, attributable to the rising proportion of the working-age population (15-64 years), notably in low- and lower-middle-income Asian countries. In this context, it is imperative for policymakers to devise targeted strategies that encourage these high-polluting countries to modify their behaviors. A combination of regulatory, economic, and behavioral instruments appears necessary to induce sustainable changes in pollution-generating practices (Alpizar et al., 2020).

Market regulation, particularly through the prohibition of single-use plastic products, constitutes an effective lever in many countries (Alpizar et al., 2020; Fadeeva and Van Berkel, 2021). Furthermore, recent literature emphasizes that behavioural instruments should complement regulatory policies and market mechanisms to produce enduring effects on polluting behaviors (Alpizar et al., 2020; Kirakozian, 2016). Consequently, public interventions should also incorporate softer informational instruments, such as awareness campaigns, educational programs, and guidelines (Uehara et al., 2022; 2023).

Indeed, developed countries can play a pivotal role in the transfer of technologies (De Mello, 1997) and the promotion of major innovations that could significantly contribute to the emergence of a circular economy based on the sustainable use of plastics (Lebreton and Andrady, 2019). In this regard, the development and diffusion of technological innovations in Asian countries could help sustain economic growth while limiting the intensification of plastic pollution.

Thirdly, the interdependence between urbanization and plastic waste management underscores the necessity of formulating and implementing effective policy responses to address this challenge (Bari et al., 2012). In this regard, urban planners are tasked with integrating plastic waste management at the core of urban development strategies, guided by circular economy principles. A comprehensive and integrated approach to plastic waste management is imperative, encompassing the entire life cycle of plastics – from production and consumption to waste management and pollution prevention (Nielsen et al., 2020). Urban spatial planning functions as a strategic instrument for implementing a circular approach. For instance, China has proactively promoted the emergence of a novel urbanization model aimed at optimizing the spatial structure of cities (Lin and Zhu, 2021). As previously indicated, OECD countries, distinguished by their high-income levels, are well positioned to assume a significant role in supporting lower-income countries in addressing the challenges associated with urbanization.

In the final analysis, public authorities are unable to adopt a passive stance regarding the control of plastic pollution and greenhouse gas emissions. It is therefore imperative that they design and implement sustainable policies and strategies that are compatible with economic growth objectives, in order to reduce plastic pollution and mitigate the impact of the accumulated stock of plastics in the environment since the 1950s.

6. Conclusion

Plastic pollution constitutes a significant and multifaceted challenge, converging at the nexus of economic, environmental, and climate-related issues. Addressing this issue necessitates the implementation of coordinated and differentiated actions among states, with the objective of reconciling the demands of economic development with the imperatives of sustainable environmental preservation. In this context, the present study seeks to analyze the impact of plastic pollution on terrestrial, aquatic, and atmospheric ecosystems, while highlighting its adverse consequences in terms of greenhouse gas emissions.

The empirical analyses reveal significant heterogeneity in impacts and confirm that the dynamics of plastic pollution are closely linked to the structural characteristics of the two groups of countries studied. Asian countries remain in a phase where demographic structure, income levels, urbanization, and industrialization are associated with increasing plastic pollution and greenhouse gas emissions. These findings appear to support the hypothesis that these nations are on the ascending phase of the Environmental Kuznets Curve, where economic development occurs at the expense of environmental quality (Yan et al., 2024).

In contrast, OECD countries have demonstrated a relative control over these phenomena, attributable to the implementation of more advanced environmental policies. However, these policies have not yet resulted in the complete elimination of the impact of plastics. Therefore, understanding these heterogeneities is crucial for policymakers, as it enables them to identify priority actions necessary for the effective and sustainable reduction of plastic pollution on a global scale.

The present study aspires to make a contribution to the academic debate while providing relevant insights for policymakers, international institutions, and economic actors engaged in combating plastic pollution. The approach adopted is integrated, distinguishing itself from traditional sectoral analyses by privileging a more holistic perspective that accounts for the interactions among various pollution drivers. Furthermore, this analysis provides an innovative empirical comparison between Asian countries severely affected by the plastic waste crisis and OECD countries with more developed institutional frameworks. The application of the system GMM model to a dynamic panel sample further enhances the robustness of the empirical results.

This investigation has enabled the formulation of several recommendations for future research. In subsequent studies, it would be pertinent to incorporate variables such as rural-to-urban migration, mixed land use, and monocentric versus polycentric urban forms. This approach would facilitate a more detailed analysis of the effects of urbanization on plastic pollution. It is also imperative to examine the spillover effects of plastic regulation policies in developing countries. For instance, China's prohibition on plastic waste imports in 2017 precipitated substantial alterations in the global trade dynamics of such waste, consequently engendering notable ramifications on the geographical distribution of plastic pollution (Lebreton et al., 2019).

This study sought to offer further insights into the nexus between plastic pollution and the deleterious effects of greenhouse gas emissions. To this end, a system GMM model was employed. Consequently, future research endeavours must encompass a more extensive array of factors and promote enhanced collaboration among a diverse array of stakeholders. Furthermore, the utilization of recently developed spatiotemporal data for the purpose of tracking plastic footprints has the potential to facilitate a more sophisticated evaluation of the implications proposed in this study (Potiracha and Baars, 2026; Rangel-Buitrago et al., 2024).

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