The need for a multi-dimensional extension of the environmental kuznets curve

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Abstract

The Environmental Kuznets Curve (EKC) hypothesis – the "grow first, clean up later" trajectory – has long dominated environmental economics. However, as highlighted in recent critical literature, the model suffers from a profound temporal mismatch. It operates within the constraints of market time (short-term fiscal and investment cycles), while ignoring the biological time required for ecosystem assimilation and regeneration. Through a thoughtful and well-structured literature review, this paper provides an answer to whether the EKC is a valid instrument to link environment and economic growth. The discussion offers useful insights into environmental economics and sustainable policy research. Before the projected cleaning-up phase of the EKC is ever achieved, there are risks of reaching tipping points where environmental degradation becomes irreversible. This study critically examines the theoretical foundations, key determinants, and major criticisms of the EKC while proposing a broader multidimensional perspective for understanding the relationship between economic growth and environmental degradation.

Introduction

The EKC hypothesizes that economic growth affects environmental quality in the shape of an inverted U. It happens in different venues over time. When a country is underdeveloped, the pressure towards its natural environment is minimal and, as pollution increases, it accentuates until it reaches a critical point where the relationship changes; later, there will be prosperity and degradation will diminish. It suggests that in the future, the increase in per capita income will lead to an improvement in environmental quality. In the 1990s Shafik and Bandyopadhyay (1992), Shafik (1994), Selden and Song (1994), Panayotou (2001; 1993), and Grossman and Krueger (1995; 1991) empirically demonstrated this idea. This concept obtains its name due to its similarity with the inequality-income relationship proposed by Kuznets (1955). Panayotou is one of the first authors to use the name Environmental Kuznets Curve (Panayotou, 1997).

This approach has been the reason for an intense debate about using it to explain degradation, especially because of the implications in terms of public policies such as "grow first, clean later" (Dasgupta et al., 2002). If a country wanted to improve in caring for the environment, it would have to grow economically first. In this regard, researchers say that EKC may face misinterpretations. Growth alone does not stop environmental degradation, as is the case with countries that live with high rates of deforestation and high per capita income (Cropper & Griffiths, 1994), or poor countries that adopt standards from rich countries and obtain better results in caring for the environment (Stern et al., 1996).

Additionally, currently, the indicators for developed countries are unfavorable for the hypothesis, since they exhibit the largest amount of pollution in the world. These indicators contradict the hypothesis: degradation in the world tends to increase in prosperous countries instead of decreasing. In contrast, interest in using the EKC has increased (Destek & Sarkodie, 2019; Pincheira & Zuniga, 2020; Mahmood et al., 2026) and EKC is applied in the world's big economies. Furthermore, research in low- and lower-middle-income countries is sporadic and limited (Sarkodie & Strezov, 2019).

This article analyzes, through a systematic review of the literature, whether the theoretical support of the Environmental Kuznets Curve (EKC) is sufficient to address the relationship between economic growth and the environment. This leads to the need for a multi-dimensional extension of a theory that seems to be invalid to study the relationship between growth and environmental degradation. This article shows that, despite the well-founded criticisms of the EKC, it is not enough to declare it invalid. The relevance of this article is the conceptual confrontation of the assumptions of the EKC to explain the reality in the relationship between economic growth and degradation. Usually, most research focuses its efforts on finding evidence of EKC, detailing the econometric technique, and estimating the best parameters.

This study is not an exhaustive review of all the extensive literature on EKC. Recent papers that have such purpose by applying meta-analysis and bibliometrics techniques that allow having a vast knowledge about the subject matter (Mejia, 2026; Pincheira & Zuniga, 2020; Shahbaz & Sinha, 2019). These are in the selection of articles based on the coincidences of authors; we consider that the research presented in this dissertation is sufficient to discuss the current state of the hypothesis.

This structure of this research work is the following. In addition to this introduction, the following section details the methodological process for selecting the literature. Later, in the results section, we classify the references into sub-lines of research, analyzing an expanded model with other factors beyond per capita income or second-order determinants, and in the same way, we examine the main conceptual and estimation criticisms. In the discussion, we validate the EKC, contrasting the theoretical assumptions and the criticisms. Finally, in the conclusions, we synthesize the main findings and make final reflections.

Methods

This research is qualitative through a systematic review of the main articles that support the foundations of the EKC. The literature is extensive, and we selected those articles considered essential to understand the hypothesis. The prevailing criterion is the relevance of the contribution due to its citations or clarity in the research.

The methodological process applied was as follows. First, there was a search for articles and working documents in specialized databases such as Scopus, Web of Science, and Google Scholar, in the period from 1997 to 2026. Then, an exploration of bibliographic citations and a contrast in the coincidences of authors with the recent meta-analysis results, opting for 70 relevant papers. We reviewed them in full text and classified them into sub-lines of research. Finally, we selected 55 articles, where the criterion was the theoretical contribution to the hypothesis, the seminal article was located, exemplifying the discussion and sub-lines of research. It is pertinent to point out that econometric evidence supports the theoretical principles of the EKC; few authors conduct a conceptual discussion, much less an epistemological one.

Researchers like Shahbaz and Sinha (2019), establish a distinction in the literature between those who verify or reject the existence of the curve. This is a previous step to discussing econometric techniques. Others make the review from the similarity of results, showing the lack of consensus, and describe the research networks present around a particular topic, group close results, describe the impact of the research by country, make a citation count, and describe the indicators used for the environmental vector (Sarkodie and Strezov, 2019; Pincheira and Zuñiga, 2020). The approach used in this research consists of the analysis of the underlying effects of the income-degradation relationship based on the most important theoretical contributions.

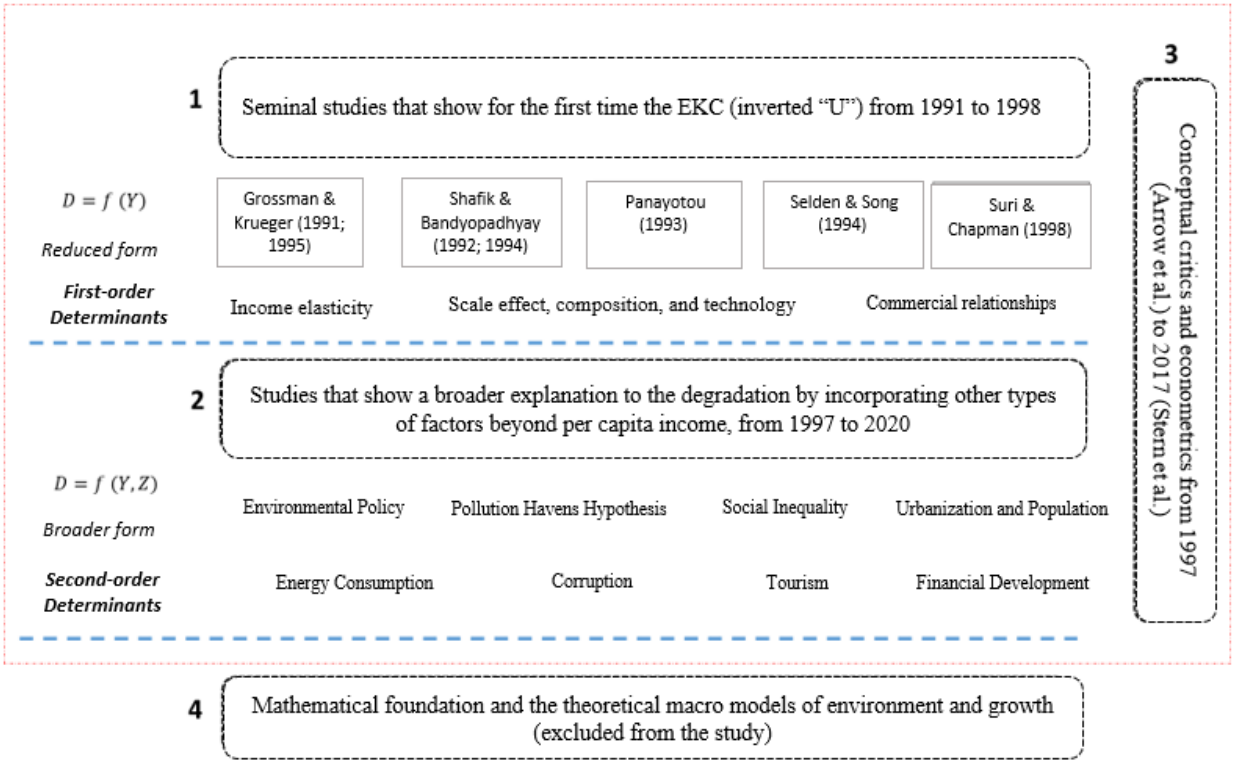
Results

The identification of sublines is the starting point for later contrasting theoretical assumptions and the most relevant criticisms of the EKC hypothesis. There were events and ideological positions that addressed the relationship between economic growth and environmental quality between 1970 and 1990.

Furthermore, the literature shows that the first explanations based on first-order determinants are a limited explanation and reduced to environmental problems. First-order determinants (assumptions): the ideological environment that precedes the proposal of the EKC in 1991, as well as the first explanations of why to consider that economic growth generates improvements in the environment (Olivares & Hernandez, 2021).

Figure 1 shows four major sub-lines of research in the literature review. The first subline is factual of seminal studies that show for the first time the EKC (inverted "U") and postulate what we have called first-order determinants; these studies explain the concave shape of the curve and go from 1991 to 1998. In its beginning, EKC was controversial because it gave the false impression that its approach was opposite to that of sustainable development: environmental problems could solve in the future only with simple growth. Trade relations present positive effects on the environment by encouraging changes in the economic structure due to technology transfer (Grossman & Krueger, 1991).

The second subline consists of second-order determinants, and they are contributions that give a broader explanation to the degradation by incorporating other types of factors beyond per capita income from 1997 to 2026.



Source: Proprietary development.

Figure 1. Sublines of research

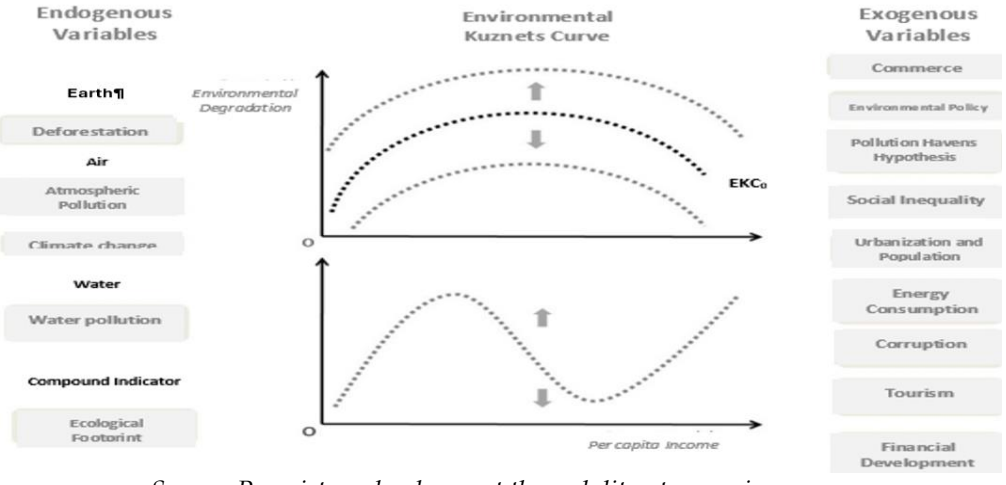
Second-order determinants: extended model (1997 to 2026)

Additional factors such as environmental policies, inequality, urbanization, energy, corruption, tourism, and financial development expand the EKC model. Strict environmental policies reduce degradation and improve the shape of the curve (Yin et al., 2015; Jung & Song, 2023). The Pollution Haven Hypothesis (PHH) indicates that developed countries avoid pollution by transferring it to other countries (Cole, 2004; Taylor, 2004; Kearsley & Riddel, 2010; Ozkan et al., 2023). Social inequality can increase (Torras & Boyce, 1998; Ridzuan, 2019; Kang, 2022; Wang et al., 2023) or decrease degradation, depending on the mechanism of redistribution and consumption (Heerink et al., 2001; Rojas-Vallejos & Lastuka, 2020; Wan et al., 2022). Urbanization and population growth increase pollution, although their relationship can be non-linear (Cropper and Griffiths, 1994; Alam et al., 2016; Katircioglu & Katircioglu, 2018; Gierałtowska et al., 2022). The use of renewable energy reduces degradation (He & Richard, 2010; Iwata et al., 2010; Sulaiman et al., 2013; Ben Jebli et al., 2016; Mahmood et al., 2023), while fossil fuels increase it (Cole et al., 1997; Shahbaz & Lean, 2012; Acaroglu et al., 2023; Rabbi and Abdullah, 2024; and Dallali & Ben Jebli, 2025). Corruption aggravates degradation, and controlling it can improve environmental quality (Cole, 2007; Leitao, 2010; López & Mitra, 2000; Bimonte and Stabile, 2019; Mahmoodi & Dahmardeh, 2022; Li et

al., 2023; Li et al., 2024). Tourism can increase or decrease emissions, depending on the development cycle and the technologies used (Katircioglu, 2014;De Vita et al., 2015; Katircioglu & Katircioglu, 2018; Chan & Wong, 2020; Bekun et al., 2022; Porto et al., 2023; Torres-Diaz et al., 2025; Sharma et al., 2025; Amin et al., 2025; AltunOz et al., 2026). Financial development can have positive effects in reducing degradation, although data and results vary (Tamazian et al., 2009; Jalil & Feridun, 2011; Dogan & Turkekul, 2016; Destek & Sarkodie, 2019; Jahanger et al., 2022; Barut et al., 2023; Prempeh et al., 2024; Toumi, 2025; and Ondes & KizilgOl, 2026).

A review of the determinants allows a characterization of the literature (see Figure 2). The following is summary.

1. Preference for atmospheric indicators. Selected literature includes these types of pollutants in its analysis. They are local and show the environmental reality of the cities where monitoring exists. Some choose sulfur dioxide (SO2) because it usually shows EKC. For global atmospheric indicators, carbon dioxide (CO2) is the preferred one.
2. Little use of biophysical and compound indicators for the environmental vector. The studies make the analysis from the degradation approach (inverted "U"), and few deal with environmental quality indicators ("U"). Furthermore, it is unusual to develop composite indicators to represent the environmental vector.
3. Little consensus on the effects of the determinants. For the same country, there may be conflicting results; just change the pollutant, the econometric technique, the size of the sample, or take a regional approach.
4. Sub-lines of research are more consolidated than others. The following are consolidated determinants: energy, environmental policy, hypothesis of pollution paradises, urbanization, and population. There is clarity in what they want to evaluate, in the technique, and in the indicator. In addition to this, corruption and social inequality are difficult to measure; the former captures a phenomenon considered a crime, and the latter requires the researcher to define a good conceptual framework. The Gini coefficient is a way to solve this limit. Finally, tourism and financial development are research in development, so the hypotheses are still being tested and there is increasing literature.
5. The conceptual comparison of the curve is unusual. Most studies focus their efforts on detailing the econometric technique and estimating the best parameters. They also provide a modest contextualization of the countries studied.
6. Evolution of econometric technique and preference for data panels. EKC analysis originates from cross-sectional methods, panels are common, and cointegration and causality techniques (ARDL, DOLS). To address the situation of a single country, they use time series analysis, though they seem less preferred. This is due to the availability of data, especially the environmental vector.



Source: Proprietary development through literature review.
Figure 2. Variables found in EKC research.

Research has now expanded the analysis through second-order determinants, but it is still not enough to address the full complexity of degradation (a common preference for atmospheric indicators, the little use of biophysical and compound indicators for the environmental vector, the scarce consensus on the effects of the determinants —same country, different results— and the unusualness of the conceptual confrontation of the postulates of the EKC). Despite the preference of the panels for time series, the estimations need to go hand in hand with the innovations in econometrics.

Discussion

The third subline is papers that criticize the hypothesis. Research that criticizes the EKC hypothesis can be divided into two main sections: conceptual CRITICISM (C) and considerations of econometric technique (E.T.).

Criticism

The following are the main criticisms and their arguments.

1. Environmental quality as an endogenous growth process, little credit to institutions and public policy(C1) (Arrow et al., 1995; Dasgupta et al., 2002; Stern et al., 1996).
2. Limited analysis, lack of ecosystem considerations such as resilience, carrying capacity, and irreversibility of energy processes(C2) (Arrow et al., 1995; Coscieme et al., 2019; Georgescu-Roegen, 1971).
3. EKCs are results that lead to incorrect assumptions about the general behavior of environmental quality(C3) (Arrow et al., 1995).
4. Research has little evidence of alternative forms of EKC(C4) (Dasgupta et al., 2002; Stern, 2004).
5. Lastly, the studies have econometric limitations, estimation problems (E.T) that distort the results. (Stern et al., 1996, p. 1158). Currently, the estimation problems are deficiencies in the handling of the technique in the presence of heteroscedasticity, simultaneity-endogeneity, bias of omitted variables, and problems of cointegration.

In general, the conceptual critique derives from the implications of the theory; the improvement of environmental quality (as an endogenous process of economic growth without foundation in ecosystem issues), which suggests other feasible ways as alternatives to the EKC. In the econometric part, they allude to problems of estimation and choice of the appropriate technique.

The main question of this article is to answer why to use a theory that, since its inception, seems to lack validity to study the relationship between growth and environmental degradation. To do this, we argue between the theoretical assumptions of the determinants and the point of the researchers in the previous literature review.

Validating the EKC

We begin by grouping the criticisms in order of difficulty. We also evaluate the main criticisms, which, although most are true, do not invalidate the hypothesis; they are simply considerations when approaching the analysis.

Environmental quality as an endogenous growth process, little credit to institutions and public policy (C1). To the argument that environmental quality is an endogenous process of economic growth (C1), we show that the premise is invalid. The EKC recognizes that income is one of the factors improving environmental quality.

Econometric limitations, estimation problems (E.T.). As for which econometric technique (E.T) is suitable, this depends on the nature of the data and its behavior (Bradford et al., 2005). The literature has pointed out certain estimation problems when verifying the presence of EKC, such as heteroscedasticity, simultaneity-endogeneity, omitted variable bias, and cointegration. At present, advanced econometric techniques help to overcome them (Jalil & Rao, 2019).

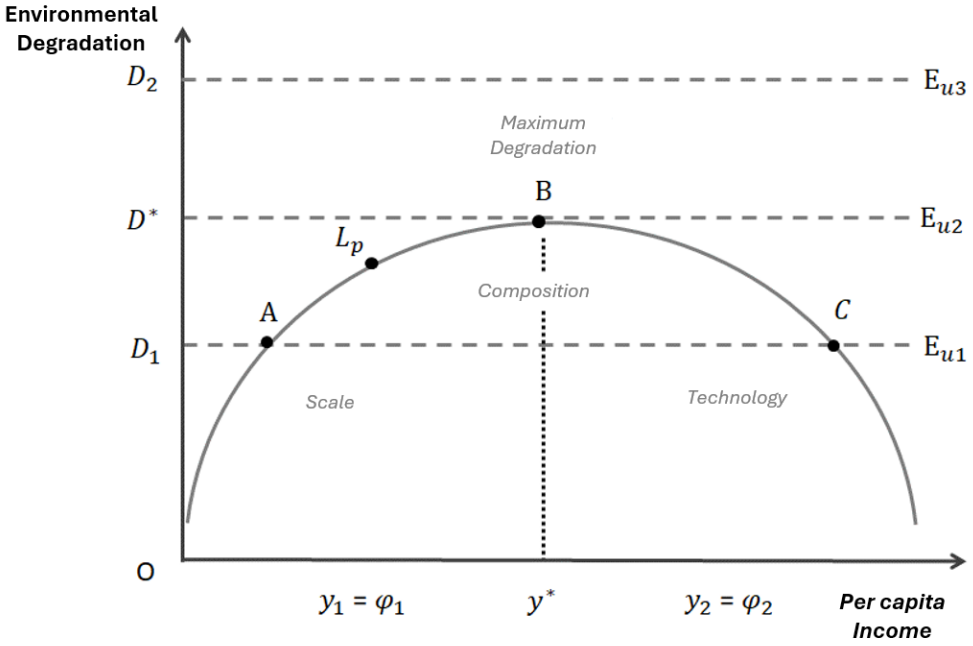
EKCs are results that lead to incorrect guesses (C3) and little evidence of alternative forms (C4). Regarding the fact that research shows results that lead to incorrect conjectures (C3) and little evidence of alternative forms (C4), this is true. Possibly C4 is moved by the modest context in the research that limits the scope of their results: they seem more interested in the econometric technique and estimating the best

parameters, forgetting that the period they analyze is a part of the total pollution path. In other words, the EKC shows partial results from broader and more complex contexts that will surely lead to new forms in the future with greater availability of data.

Finally, by incorporating ecological criteria into the EKC, it makes the emissions path more realistic and shows that the model is one of imperfect competition, contrary to the theoretical assumptions. Starting from a static model, taking Andreoni and Levinson (2001) and Panayotou (1993) as a reference, we can demonstrate the point through the decisions of economic agents.

EKC with ecological support (C4). Suppose that there are three points in the EKC: one to the left A, another in the center that coincides with the top B and a third to the right C. (see figure 4). If there is a point A it has a serious problem; the income is so low that the size of τ would have to be small, but if it imposed an amount under the environment, it would exceed the threshold with catastrophic results: the difficult decision to tax poor households in times of ecological crisis. At point C, Government has to put a high tax, and households must pay it. Due to the location on the curve, the point seems to be beneficial for the environment; however, due to the concavity, it exceeds the ecological threshold at some point, and due to the irreversibility of energy processes, such point is uncertain (Bestelmeyer, 2006).

If it exists at point B, it should put a high tax to return to an area between points A and B. The criticism of the EKC is that a planner would choose inaction because his expectation is that the pollution path will decrease past this point. However, in terms of ecology, this is false. It is difficult for the environment to regain its capacity once we exceed the ecological threshold. A cautious planner will impose a high tax and try to position itself close to A and L_p. Note that is a point "within which humanity is expected to operate safely" (RockstrOm et al., 2009, p. 1) and have time to react to a possible ecological crisis. L_p is known as the planetary limit. Due to these results, the model based on perfect competition is incorrect; it is difficult to know the social optimum from the asymmetric information. Even so, it is undeniable that incorporating ecosystem considerations, such as resilience, provides better information for decision-making in caring for the environment.



Source: Proprietary development

Figure 3. EKC with ecological support

Thus, incorporating ecosystem considerations such as resilience and thresholds provides better information for decision-making in environmental protection. Using a static model of behavior, the assumption of perfect competition turns out to be incorrect.

Concluding remarks

In this article, we analyze the income-environment relationship from the theoretical evolution of the EKC to evaluate why to continue using this hypothesis, although for opposers it lacks validity to address the impact of economic activity on the environment.

The literature has expanded the analysis to include second-order determinants such as energy, environmental policies, urbanization, social inequality, tourism, and financial development. Most studies use advanced econometric techniques, preferably panels, to overcome limitations such as endogeneity and heteroskedasticity. There are conflicting results and little consensus on the effects of the determinants, varying by country, indicator and technique. The relationship could be influenced by factors such as the redistribution of emissions in large countries, and by ecological considerations such as resilience and ecological thresholds. Despite the advances, there are still challenges in measuring complex ecological variables, such as resilience and ecological thresholds. Innovation in composite indicators and geospatial tools can expand the quality of analysis in the future.

Regarding the argument that suggests the need to include criteria with ecological support (C4) in the analysis of the EKC, it is true. This finding suggests that the planning agent possesses asymmetric information, meaning it is unable to correct the degradation with an optimal tax. It does not know the true value defined by the variables of ecological support and of society's environmental awareness. In real circumstances, the measurement requires considerable research effort, limiting its application. If we can understand that an EKC is a partial image of a wide, complex pollution path, where the assimilation and regeneration times of nature are different from the market times, we will be able to understand the limitations of the theory and specify the model better in terms of variables that reflect environmental degradation and econometric techniques. In that way, the EKC hypothesis remains valid.

Many unanswered questions about the factors that determine the economic growth-degradation relationship in the EKC still exist, but it is clear to us that improving the analysis is necessary to migrate to the multi and transdisciplinary. The estimates are still based on the same indicators, and to capture something as complex as an environmental phenomenon, one must innovate in the creation of composite indicators that reflect the existing heterogeneity of ecosystems and degradation in the countries; for example, the availability of data provided by geospatial tools, which opens the door to better research.

The main limitation of our study could be having left out research papers that might be relevant, although we consider that the selection was representative to test the validity of the hypothesis.

Lastly, the objective of the EKC is to use it as a technique to evaluate public policies that mitigate pollution. Engaging in finding the "turning points" or the form of the curve (U, N) using econometric techniques limits the scope of the approach. It would reinforce the misconception that pollution could reduce by economic growth.

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