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The Environmental Kuznets Curve in Rich and Poor Countries: Insights from NASA-MODIS GPP Data

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Abstract

This study proposes an alternative approach to examining the Environmental Kuznets Curve (EKC). Instead of using conventional pollution indicators, we employ gross primary production (GPP) data from the NASA-MODIS dataset as a proxy for environmental quality across 131 countries. By estimating the nonlinear relationship between environmental protection and economic development, we confirm the conventional EKC pattern only in wealthy nations, where environmental quality improves as economies achieve higher levels of prosperity. In less developed countries, however, environmental quality tends to deteriorate further as economic growth accelerates. These results suggest that the EKC may be a localized phenomenon, raising concerns about policy suggestions that prioritize economic growth over environmental protection in less developed regions.

Keywords: Gross Primary Production; NASA-MODIS; Environmental Kuznets Curve; Nonlinearity; Income Groups

JEL Classifications: Q0; Q5; O0

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1 Introduction

The economy is fundamentally dependent on society and the environment, as human existence and societal functions are inherently tied to the natural world (Giddings et al., 2002). Economic development can be analyzed through the lens of sustainability (Atkinson et al., 1997), with policymakers increasingly recognizing the complementarity between environmental protection and economic growth (Munasinghe, 1993). Sustainable development advocates for balancing economic growth with conservation efforts, prioritizing modernization over zero-growth approaches (Du Pisani, 2016). Recent research suggests that sustainable growth is attainable through the implementation of appropriate policies (Ekins, 2002). Striking this balance is particularly crucial in less developed countries to mitigate environmental degradation, economic setbacks, and associated health risks. While pathways may differ across contexts, the overarching goal remains to harmonize economic growth with environmental stewardship (Goodland, 1995; Pearce and Warford, 1993).

Growing attention to the environmental impacts of economic activity has highlighted the value of natural ecosystems, with increased focus on sustainability by bothe the public and policy-makers (Hanley et al., 2019). Since the seminal work of Grossman and Krueger (1991, 1995), many researchers have investigated the link between economic development and environmental damage through the Environmental Kuznets Curve (EKC) framework. Studies have explored the relationship between economic development and environmental impacts such as carbon dioxide (see, among others, Jobert and Karanfil, 2012; Kaika and Zervas, 2013), sulfur dioxide emissions (see, among others, Begun and

Eicher, 2008), and deforestration (see, among others, Choumert et al., 2013; Tsiantikoudis et al., 2019).[1]

Torras and Boyce (1998) apply the Environmental Kuznets Curve (EKC) framework, demonstrating how rising incomes can improve air and water quality, particularly in low-income countries, where literacy and civil liberties also playing key roles. Panayotou (1997) finds policies can reduce environmental degradation and flatten the EKC by lowering the environmental cost of growth, as seen with SO_2 emissions.

Global studies further explore these dynamics. Halkos (2003), analyzing panel data consisting of 73 countries between 1960 and 1990, reports limited but supportive evidence for the EKC. Grunewald et al. (2017) associate higher income inequality with lower carbon emissions in low-income countries but higher emissions in wealthier nations. Selden and Song (1994) find inverted U-shaped patterns in air pollutant emissions relative to GDP, while Suri and Chapman (1998) show industrialized nations tend to reduce energy needs by importing manufactured goods.

Using data of 28 provinces in China from 1996 to 2012, Li et al. (2016) support the EKC, but point out the harmful environmental impacts of urbanization and trade. Roca et al. (2001) find no significant link between income and emissions in Spain, except for SO_2. Baek and Gweisah (2013) associate equitable income distribution in the U.S. with improved environmental quality, while Kaika and Zervas (2009) report a positive income-CO_2 emission relationship in many previous studies. De Bruyn et al. (1998) observe emissions reductions in Western economies driven by structural and technological changes despite a positive correlation with economic growth. Wang et al. (2023) report nonlinear

[1] See Guo and Shahbaz (2024) a comprehensive literature review on the relationship between environmental damage and economic growth.

effects of income inequality on the Environmental Kuznets Curve (EKC), highlighting that excessive income inequality can undermine the positive phase of the EKC, characterized by low environmental damage and high economic development.

Our primary objective is to examine the relationship between environmental protection and economic growth across four income classifications among 131 countries from 1982 to 2011. Rather than using pollution variables to measure environmental damage, we employ gross primary production (GPP) data from the NASA-MODIS as a proxy for environmental quality. This approach allows us to evaluate the nonlinear relationships implied by the EKC, which suggests that environmental quality improves (or environmental damage declines) once an economy surpasses a certain development threshold.

Our findings contribute new insights to the EKC literature, showing evidence of the EKC only in wealthier nations while indicating that economic growth accelerates environmental degradation in less developed countries. Furthermore, we find that the impact of population growth on environmental quality varies by economic development stage. Specifically, population growth has detrimental environmental effects in less developed countries, which account for over 70% of our observations, whereas positive effects are observed in richer nations.

This paper is organized as follows. Section 2 provides a detailed explanation of the data and preliminary analysis. Section 3 introduces the panel estimated generalized least squares regression model, which incorporates the nonlinear relationship between environmental quality and economic development, while accounting for population effects.

Key findings are also presented in this section. Section 4 provides additional empirical findings, particularly focusing on elasticity estimates. Section 5 concludes the paper.

2 Data Descriptions and Preliminary Analysis

2.1 Data Sources and Key Features

We use gross primary production (GPP) data for 131 countries, obtained from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS).[2] We calculated GPP per square kilometer (GPP_{psk}) by combining these data with corresponding land area measurements (in square kilometers) for the period from 1982 to 2011.[3]

GPP, representing the amount of carbon assimilated by plants through photosynthesis, serves as a key indicator of environmental health. Higher GPP values generally indicate stronger environmental protection, reflecting greater carbon absorption and storage capacity and enhanced ecosystem productivity. This makes GPP a crucial metric for evaluating the health of natural systems and their contribution to mitigating climate change.

In our analysis, we replace conventional pollution-related variables (environmental damage) with GPP (environmental quality) to examine the Environmental Kuznets Curve (EKC) relationship. As a result, the U-shaped pattern observed in our findings is consistent with the inverted U-shaped EKC typically found when pollution variables are used. This

[2] Refer to the NASA-MODIS website at https://modis.gsfc.nasa.gov/data/dataprod/mod17.php for detailed explanations on the construction of the data.
[3] We extend our gratitude to the Landscape Ecology & Ecosystem Science Lab at Michigan State University for generously providing the GPP and land area measurements data.

suggests that as economies achieve higher levels of development, societies begin placing greater emphasis on environmental quality over consumption goods.

We also acquired real gross domestic product per capita (GDP_{ca}) in 2005 U.S. dollars from the World Bank to measure economic growth for each country, based on the World Bank's 2022-2023 income classifications (World Bank, 2022). Note that we relate economic development with environmental protection by employing GPP instead of pollution, the U-shaped pattern observed is consistent with the conventional EKC in our research.

The World Bank classifies the global economy into four income groups: "Low," "Lower-Middle," "Upper-Middle," and "High" income countries. These classifications are updated annually based on the previous year's gross national income (GNI) per capita. While countries may shift categories due to these updates, our analysis employs the latest classifications as a benchmark. Alongside our empirical analysis based on 3,930 total observations, we conducted subgroup analyses for each income group, with observations distributed as follows: "Low" (690), "Lower-Middle" (1,170), "Upper-Middle" (930), and "High" (1,140).

2.2 Brief Overview of the Data

Table 1 presents descriptive statistics for the 131 examined countries. The average real GDP per capita (GDP_{ca}) was $395, $1,160, $3,781, and $25,625 in the "Low," "Lower-Middle," "Upper-Middle," and "High" income groups, respectively, highlighting substantial income disparities across countries. For instance, the average GDP_{ca}^{High} is 65 times greater than that of GDP_{ca}^{Low}. Within the "Low" income group, similarly substantial disparities were also observed, with the highest average income being 30 times greater than that of the lowest income member. In contrast, income variation in the "High" income group was relatively modest, with the highest average income being only 5 times greater than that of the lowest income member.

However, the average GPP_{psk} reveals an unusual pattern: it continues to increase from the "Low" to the "Upper-Middle" income group but declines in the "High" income group to about 1,103 per square kilometer—lower than that of the "Low" income group (1,262 per square kilometer). This suggests a nonlinear relationship between GPP_{psk} and GDP_{ca}. Average population (Pop) trends are similar, with "Upper-middle" income countries exhibiting the highest mean population (60.3 million), followed by "Lower-middle" (54.4 million), and "Low" (11.3 million). Substantial variability in maximum and minimum values was observed within and across income groups.

Table 1 around here

Figure 1 illustrates the global distribution in GDP_{ca} and GPP_{psk} for 1982 and 1992 across 131 countries. The observed lack of a monotonic relationship between GPP_{psk} and GDP_{ca} implies the presence of a potential nonlinear relationship, such as the U-shaped pattern commonly associated with the Environmental Kuznets Curve (EKC), documented in the current literature. Figure 2 presents similar mappings for 2002 and 2011, highlighting some notable changes particularly regarding GDP_{ca} (e.g., South Korea and China) in comparison with Figure 1.

Figures 1 and 2 here

To provide a clearer understanding of these shifts in trends, Figure 3 illustrates the percentage changes over the three decades. The top panel of Figure 3 presents percentage variations in GPP_{psk} and GDP_{ca} during the period from 1982 to 1992. Overall strong economic performance is observed in High-Income countries, while Low-Income countries experienced negative economic growth, with Middle-Income (LM and UM) countries showing mixed results.

The growth rate of GPP was generally modest in most countries, with some notable exceptions. For instance, Afghanistan and Tunisia saw increases of 34.26% and 25.55%, respectively, while Greenland and Botswana experienced decreases of 20.27% and 15.47%, respectively, during this period. See Tables A1 and A2 in the appendix for the country IDs.

The middle panel of Figure 3 depicts changes in GPP_{psk} and GDP_{ca} during the second decade, from 1992 to 2002. This period reflects solid progress in real GDP globally, although some Low-Income countries faced unfortunate outcomes. The growth rates of GPP_{psk} followed a pattern similar to the previous decade, with a few notable outliers. For example, Greenland's GPP_{psk} rose sharply by 55.54%, while Tunisia experienced a significant decrease of 39.53%.[4]

The bottom panel of Figure 3 highlights the drastic changes in GPP_{psk} and GDP_{ca} across the world during the third decade. Most countries, regardless of income groups,

[4] Another notable observation is Equatorial Guinea, where its GDP per capita skyrocketed by 744%, rising from $937 in 1992 to $7,910 in 2002. This extraordinary growth was driven by the discovery of large oil reserves in the 1990s, making it Sub-Saharan Africa's third-largest oil producer, following Nigeria and Angola.

exhibited remarkable economic performance in terms of real GDP per capita and GPP per square kilometer. The overall performance in High-Income countries stabilized, while substantial improvements were observed in other regions. Notable examples include Morocco (42.25%), Australia (42.39%), and Tunisia (73.55%), which experienced significant increases in GPP_{psk}.

Figure 3 here

In Figure 4, we present the long-run relationship between GPP_{psk} and GDP_{ca} growth rates over the entire 30-year sample period from 1980 to 2011. Refer also to Tables A1 and A2 in the appendix. While these scatter plot diagrams provide extremely rough visual insights, a notable inverted U-shaped pattern emerges for lower-income countries (Low and Lower-Middle), contrasting with an inverted pattern for higher-income countries (Upper-Middle and High). Specifically, in lower-income countries, environmental quality tends to deteriorate when the economy grows at sufficiently high rates. Conversely, higher-income countries appear to support high economic growth alongside improved environmental protection, as evidenced by the much thicker right tails in the graphs.

Although these figures highlight intriguing patterns, it is important to note that they are based solely on the simple growth rates of GPP and GDP using the initial and final observations. In the next section, we delve deeper into these potential nonlinear patterns by analyzing the complete set of observations.

Figure 4 here

3 The Empirics

We employ the panel feasible generalized least squares (PFGLS) approach, also referred to as panel estimated GLS (PEGLS), allowing the nonlinear relationship between environmental factors and economic development across 131 countries and their four sub-income groups. Unlike ordinary least squares (OLS), the PFGLS estimator is more efficient for datasets in the presence of heteroskedasticity (Grubb and Magee, 1988), as well as serial and cross-sectional correlations (Bai et al., 2021).

3.1 The Empirical Regression Model

Our primary objective is to estimate the elasticity of the environment with respect to economic development and population. For this, we introduce the following regression model.

$$GPP_{i,t} = \alpha_i + \beta_1 GDP_{i,t} + \beta_2 GDP_{i,t}^2 + \beta_3 Pop_{i,t} + \sum_{j=1}^{3} \gamma_j D_j + \varepsilon_{i,t}, \tag{1}$$

where $GPP_{i,t}$ and $GDP_{i,t}$denote the log-transformed GPP_{psk} and GDP_{ca}, respectively, for country i at time t. $Pop_{i,t}$ represents the log-transformed population. The three dummy variables, D_1, D_2, and D_3 denote membership in “Lower-Middle”, “Upper-Middle”, and “High” income groups, with “Low” income group serving the benchmark category.

From Equation (1), the elasticity of GPP per square kilometer, GPP_{psk}, with respect to a 1% change in real GDP per capita, GDP_{ca}, is derived as the following.

$$\frac{dGPP_i}{dGDP_i} = \hat{\beta}_1 + 2\hat{\beta}_2 \mathrm{GDP}_i, \tag{2}$$

where $\hat{\beta}_1$ and $\hat{\beta}_2$ are PFGLS estimates from (1). (2) provides the percentage response of GPP_{psk} when there is a 1% economic growth in country i. Similarly, the elasticity of GPP_{psk} with respect to a 1% change in population, $Pop_{i,t}$, is given directly by $\hat{\beta}_3$.

For different income categories, using the "Low" income category as the baseline for comparison, the elasticity adjustments for income group membership are represented as e^{γ_1}, e^{γ_2}, and e^{γ_3} for the "Lower-Middle," "Upper-Middle," and "High" income categories, respectively. These adjustments quantify the relative differences in elasticity across income groups, offering insights into how membership in each category affects the underlying GPP response being modeled. By examining these elasticity adjustments, researchers can better understand the economic dynamics and variability across different stages of economic development , enabling a deeper understanding of how income group membership influences behavioral patterns and resource allocation.

3.2 Empirical Analysis on Four Income Categories

We examine 131 countries across four income categories, "Low," "Lower-Middle," "Upper-Middle," and "High" income groups, over the period from 1982 to 2011. Our empirical analysis is conducted and compared across these income groups. Furthermore, we identify turning points for each group based on the second derivative, corresponding to the maximum or minimum points of the relationship. The panel EGLS estimates are reported in Table 2, while the resulting elasticity estimates and their economic inferences are summarized in Table 3.

Our findings reveal a statistically significant relationship between environmental quality and economic growth, though the nature of this relationship varies across income groups during the 1982–2011 period. Notably, the analysis uncovers a U-shaped relationship between GPP_{psk} and GDP_{ca} globally, consistent with the Environmental Kuznets Curve (EKC). This suggests that environmental degradation initially worsens with economic development but subsequently improves after reaching a turning point. The marginal benefits of improved environmental quality begin to outweigh those of other consumption goods at these turning points. The estimated turning points are 0.0394 and 0.0389, without and with population effects considered, respectively.

It should be noted that a similar U-shaped relationship is observed only among "High" income countries, with a turning point of 0.0536 in the model excluding population effects. For all other income groups, evidence of this U-shaped relationship between GPP_{psk} and GDP_{ca} is absent. Putting it differently, accelerated environmental degradation may occur in countries where economic development has not reached sufficiently high levels.

Tables 2 and 3 about here

When comparing models with and without population, the inclusion of population reveals a statistically significant but qualitatively opposite relationship between the environment and population across different income groups from 1982 to 2011. In "High" income countries, there is a positive relationship between population and the environment, while other income categories exhibit a statistically negative relationship. This indicates that for countries in less developed economic stages, an increasing population negatively impacts environmental quality when other factors are held constant.

For most countries during the studied period, population growth tends to exert pressure on the environment, except in “High” income countries. This discrepancy may be interpreted as larger populations typically reducing real GDP per capita while simultaneously intensifying the consumption of finite natural resources, thereby accelerating environmental degradation. In contrast, higher-income countries may counteract these pressures through technological advancements, improved infrastructure, and greater resource efficiency. Also, these nations often implement stronger environmental regulations and policies, which can help to offset the adverse effects of population growth and promote sustainable development practices.

4 Elasticity of Environment with respect to the Influencing Factors

This section discusses the elasticity estimates of the environment with respect to economic growth, population, and different income categories, as shown in Table 3, highlighting the specific trends during the studied period.

Globally, a 1% increase in real GDP per capita (GDP_{ca}) leads to a decrease in GPP per square kilometer (GPP_{psk}) by 1.104% in the model without population and 1.068% in the model with population. A 1% increase in population (Pop) results in a 0.029% decrease in GPP_{psk}.

When comparing income categories, GPP_{psk} is higher in "Lower-Middle" income countries than in "Low" income countries by 1.075% and 1.088% in the models without and with population, respectively. Similarly, "Upper-Middle" income countries exhibit increases of 1.425 and 1.466%, while "High" income countries show increases of 1.452 and 1.456%, emphasizing the positive association with higher income levels from the perspective of environmental protection (GPP_{psk}).

For different income categories, there is a statistically significant relationship between the environment, economy, and population. A negative association is observed between environmental quality and economic development globally; specifically, GPP_{psk} decreases by 4.273% for a 1% increase in GDP_{ca} in the model without population. This contrasts with other income categories, which exhibit a statistically significant positive relationship between GPP_{psk} and GDP_{ca}, as shown in Table 3.

In "Low" income countries from 1982 to 2011, a 1% increase in GDP_{ca} corresponds to an 8.971% increase in GPP_{psk}, while a 1% increase in population (Pop) results in a decrease of 0.179%. For "Lower-Middle" income countries, a 1% increase in GDP_{ca} leads to a 3.775% increase in GPP_{psk}, whereas a 1% increase in Pop causes a 0.041% decrease. In "Upper-Middle" income countries, a 1% increase in GDP_{ca} increases GPP_{psk} by 1.667%, while a 1% increase in Pop results in a 0.140% decrease.

5 Discussions and Conclusions

In this study, we investigate the nonlinear relationship between environmental quality and economic development using a novel dataset covering 131 countries from 1982 to 2011.

Employing the panel feasible generalized least squares estimator across four income-based country groups, we find evidence of the Environmental Kuznets Curve (EKC) only in developed countries. In contrast, less developed countries often experience accelerated environmental degradation after they reach sufficiently high levels of income. Furthermore, our analysis reveals that rising population pressures often compromise environmental quality, except in wealthy developed countries.

Our findings imply that the EKC may be a localized phenomenon. Notably, we observe *inverted* EKC curves in less developed countries, which account for over 70% of global observations. These results challenge the universal applicability of the EKC framework and raise concerns about policy prescriptions that prioritize economic growth over environmental quality.[5] We claim for a paradigm shift in environmental policy to be tailed to the economic development status of individual countries.

Our analysis is based on a large panel dataset of 131 countries, focusing on a limited number of key factors, such as economic development and population, to better examine the relationship between environmental quality and economic development. While our findings successfully identify nonlinear relationships between these variables across countries at various stages of economic development, further exploration into additional determinants that influence such relationship remains necessary. Future research will aim to incorporate more comprehensive datasets to deepen our understanding of these dynamics.

[5] See Beckerman (1992) and Dasgupta et al. (2002) for related discussions.

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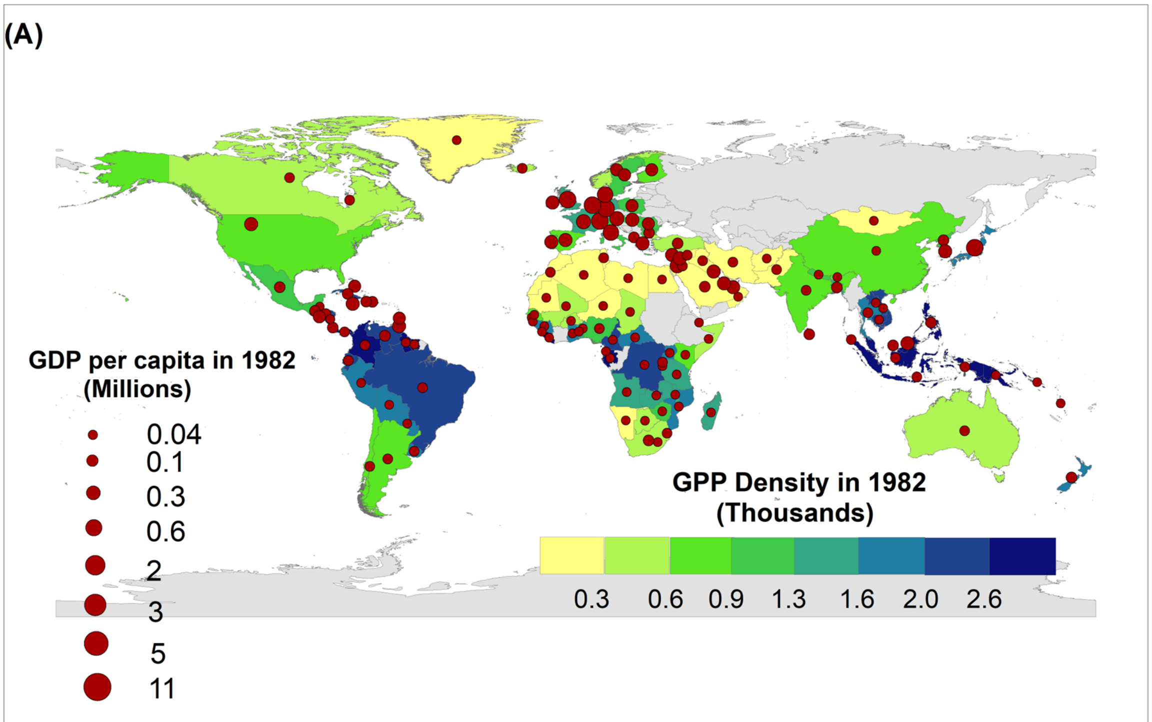
Figure 1. Real GDP per capita and GPP per square kilometer in 1982 and 1992



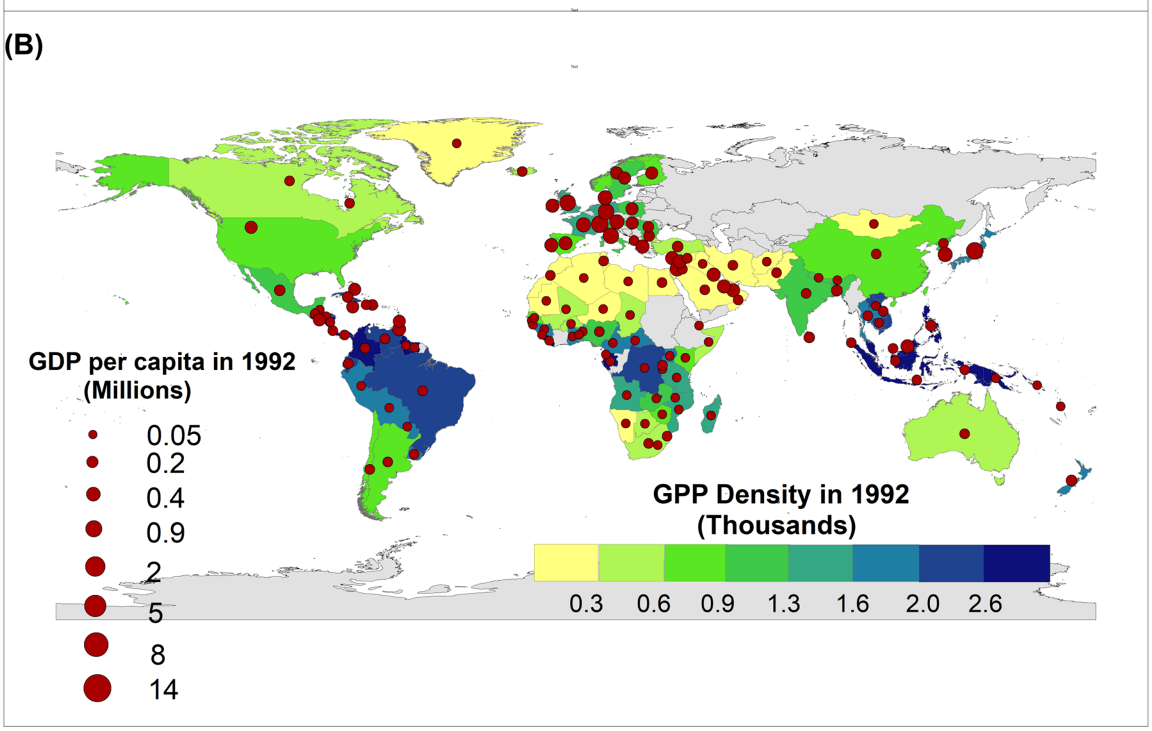
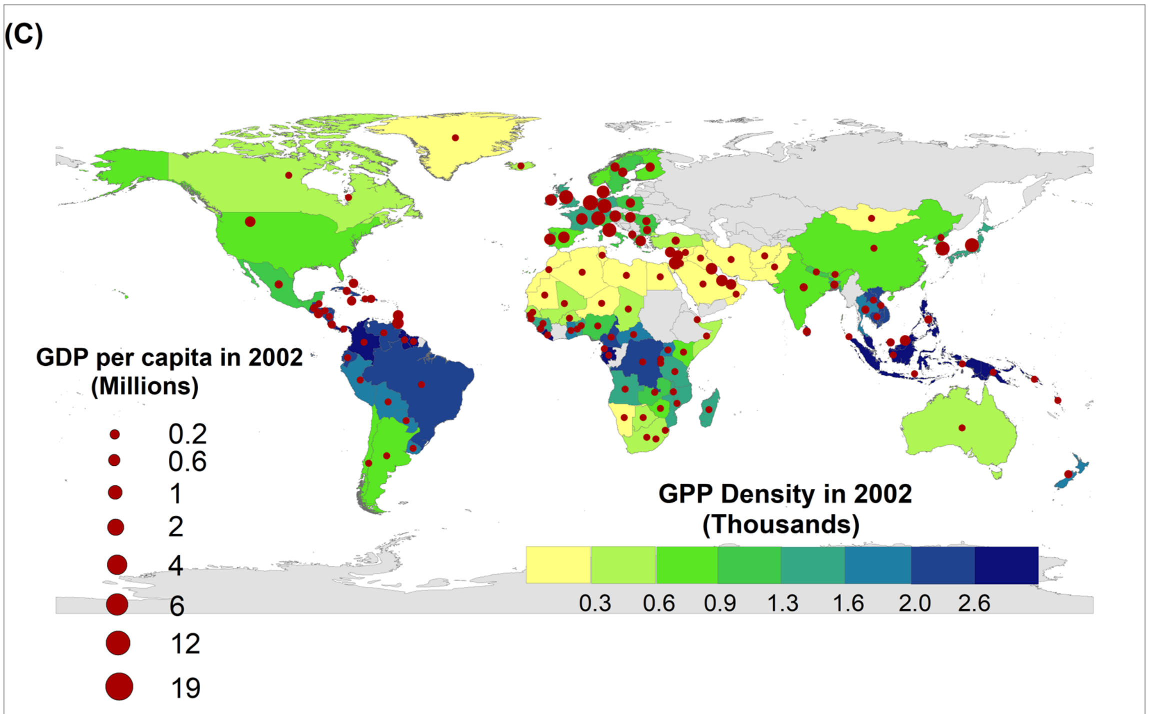


Figure 2. Real GDP per capita and GPP per square kilometer in 2002 and 2011



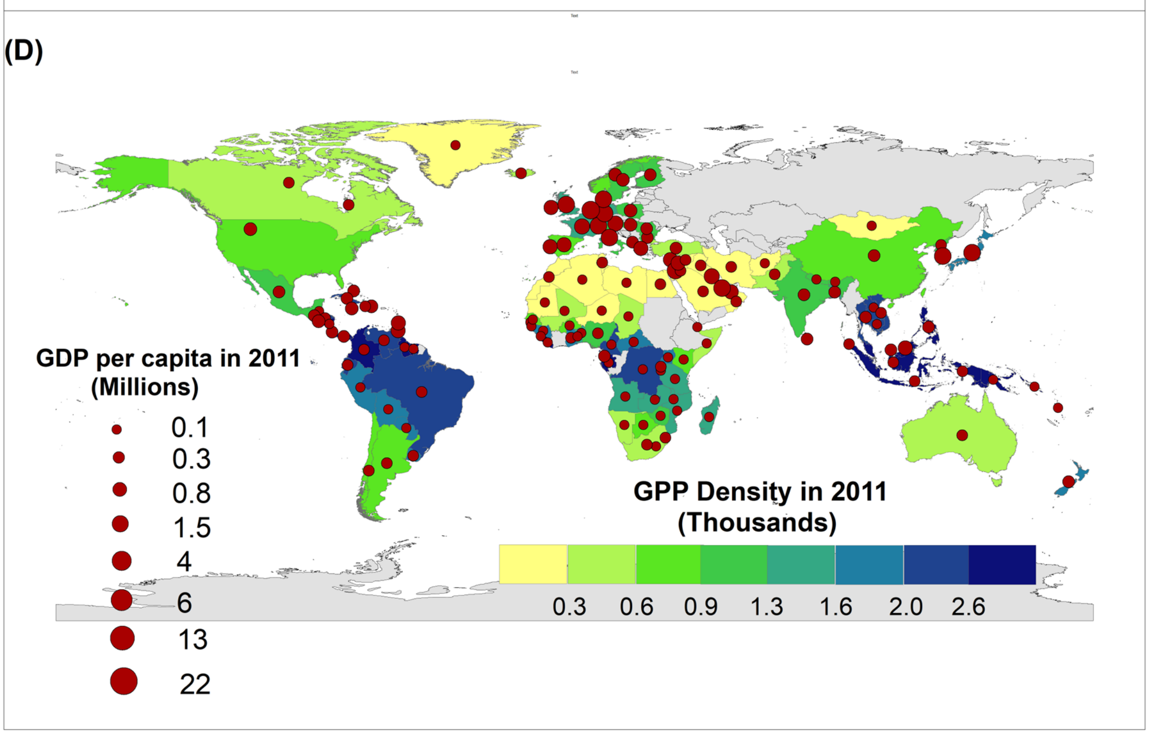
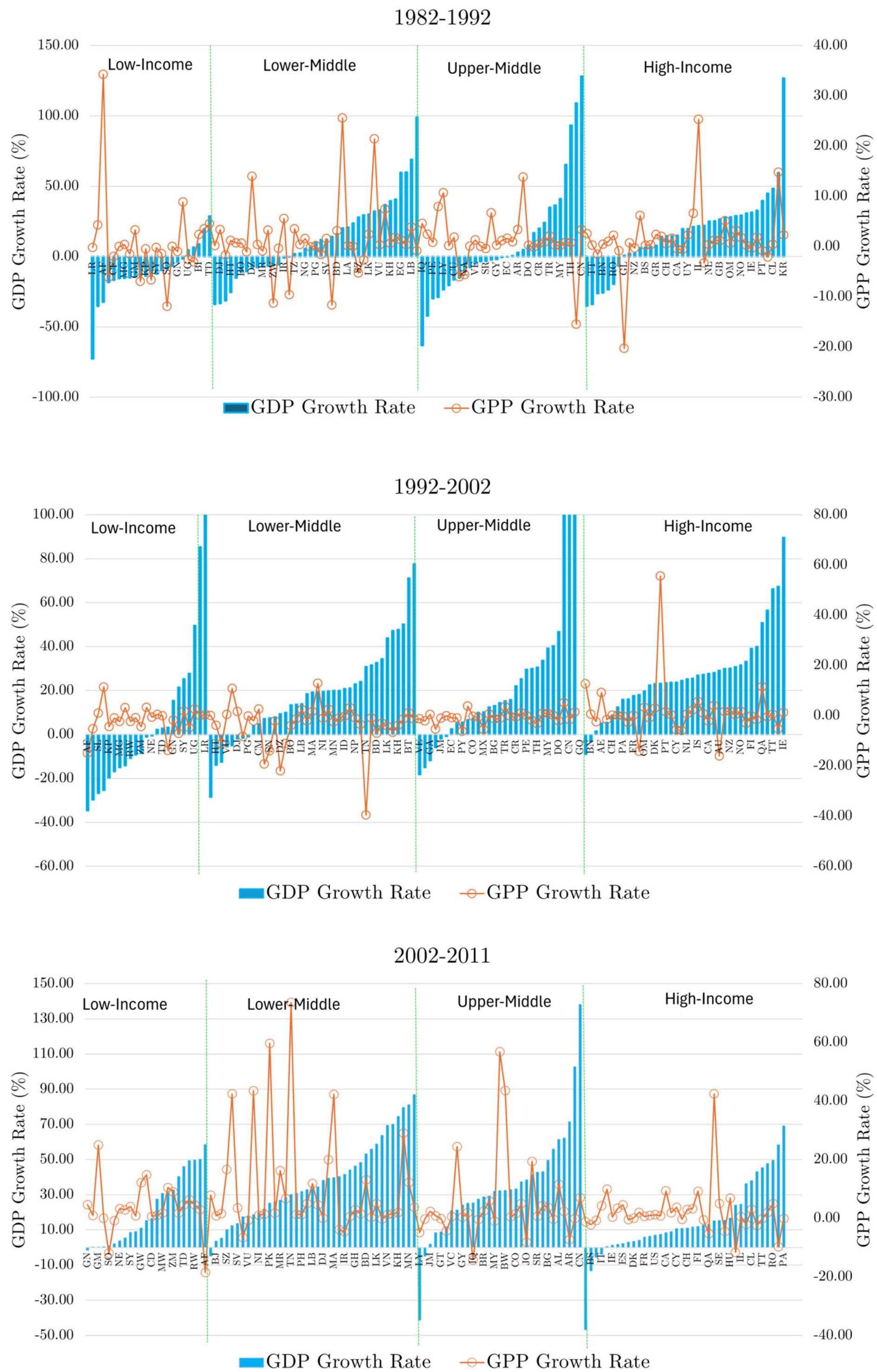
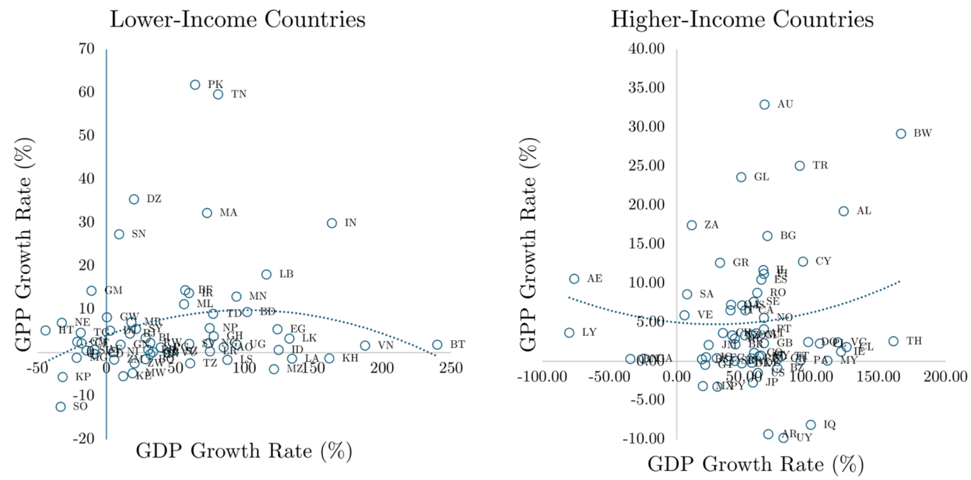


Figure 3. Growth Rates of GPP and real GDP over Three Decades



Note: The unit for GPP is per square kilometer, while GDP is measured as the real value per capita. Observations within each group are arranged in ascending order based on the GDP growth rate.

Figure 4. Lower-Income vs. Higher-Income Countries



Note: GDP and GPP growth rates are calculated for the full sample period from 1980 to 2011. The dotted lines represent quadratic trend lines of the observations. Lower-Income Countries include the Low- and Lower-Middle-Income groups, while Higher-Income Countries comprise the High- and Upper-Middle-Income groups. To improve clarity, three outliers—Equatorial Guinea, China, and South Korea, which exhibit exceptionally high GDP growth rates—were excluded from the Higher-Income Countries group.

Table 1. Descriptive Statistics of 131 Countries from 1981 to 2022

Variable	#Obs	Mean	S.D.	Max	Min
GPP_{psk}	3,930	1,380	916	3,174	52
GDP_{ca}	3,930	8,743	13,472	69,015	56
Pop	3,930	40,037	138,636	1,344,130	52
Income Groups	#Obs (Share, %)	Mean	S.D.	Max	Min
GPP_{psk}^{Low}	690 (17.56)	1,262	732	2,857	52
GDP_{ca}^{Low}	690 (17.56)	395	250	1,676	56
Pop_{Low}	690 (17.56)	11,274	9,826	63,932	648
GPP_{psk}^{LM}	1,170 (29.77)	1,407	959	3,174	103
GDP_{ca}^{LM}	1,170 (29.77)	1,160	978	7,151	177
Pop_{LM}	1,170 (29.77)	54,380	158,511	1,221,156	121
GPP_{psk}^{UM}	930 (23.66)	1,773	1,033	3,074	82
GDP_{ca}^{UM}	930 (23.66)	3,781	2,204	16,848	250
Pop_{UM}	930 (23.66)	60,297	212,620	1,344,130	102
GPP_{psk}^{High}	1,140 (29.01)	1,103	737	3,109	66
GDP_{ca}^{High}	1,140 (29.01)	25,625	14,646	69,015	2,904
Pop_{High}	1,140 (29.01)	26,198	48,389	311,588	52

Note: GPP_{psk} represents the gross primary production per square kilometer, while GDP_{ca} denotes the real gross domestic production per capita in 2005 U.S. dollars. Pop is the population expressed in 1,000 persons. Countries are categorized into four income groups by the World Bank: Low, Lower-Middle (LM), Upper-Middle (UM), and High.

Table 2. Empirical Results of the Panel EGLS from 1982 to 2011

Independent	Dependent (GPP_{psk})									
	Low-income	Low-income	Lower-Middle	Lower-Middle	Upper-Middle	Upper-Middle	High Income	High Income	World	World
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
GDP_{ca}	2.831***	2.725***	1.266***	1.313***	4.935***	0.716*	-2.150***	-0.442	-0.639***	-0.622***
	(0.410)	(0.462)	(0.187)	(0.200)	(0.427)	(0.425)	(0.275)	(0.291)	(0.041)	(0.044)
$GDP_{ca} * GDP_{ca}$	-0.699***	-0.678***	-0.256***	-0.267***	-0.730***	-0.103*	0.231***	0.032	0.050***	0.048***
	(0.082)	(0.091)	(0.031)	(0.033)	(0.061)	(0.062)	(0.033)	(0.034)	(0.006)	(0.006)
Population	--	-0.179***	--	-0.041***	--	-0.140***	--	0.166***	--	-0.029***
		(0.016)		(0.006)		(0.007)		(0.006)		(0.003)
Lower-Middle	--	--	--	--	--	--	--	--	0.072***	0.084***
									(0.009)	(0.009)
Upper-Middle	--	--	--	--	--	--	--	--	0.354***	0.383***
									(0.013)	(0.013)
High	--	--	--	--	--	--	--	--	0.373***	0.376***
									(0.014)	(0.014)
Intercept	0.418	1.776***	1.566***	1.809***	-5.152***	2.898***	7.897***	3.101***	4.379***	4.543***
	(0.514)	(0.623)	(0.275)	(0.306)	(0.745)	(0.753)	(0.572)	(0.612)	(0.069)	(0.080)
Adjusted R^2	0.45	0.45	0.24	0.28	0.19	0.38	0.28	0.52	0.43	0.42
Obs.	690	690	1170	1170	930	930	1140	1140	3930	3930

Note: Obs. represents the number of observations. GPP_{psk} denotes the log GPP per square kilometer, and GDP_{ca} represents the log real GDP per capita. The income groups - Low-Income, Lower-Middle, Upper-Middle, and High-Income - are based on classifications from the World Bank. For each model, (1) and (2) refer to cases where the model was estimated without or with population, respectively. $***\ P < 0.01, **\ P < 0.05, *\ P < 0.10$.

Table 3. Elasticity of the Environment (GPP) with respect to Economic Development (GDP), and Population (POP)

Dependent	Economic Growth Elasticity	Population Elasticity	Income Group Elasticity			Turning Point	Curve's Shape
Country\Independent	GPP/GDP	GPP/POP	Lower-Middle	Upper-Middle	High-Income	$d^2GPP/dGDP^2$	
Low (1)	9.271%	--	--	--	--	0.123	Inverted-U shape
Low (2)	8.971%	-0.179%	--	--	--	0.124	Inverted-U shape
Lower-Middle (1)	3.625%	--	--	--	--	0.101	Inverted-U shape
Lower-Middle (2)	3.775%	-0.041%	--	--	--	0.102	Inverted-U shape
Upper-Middle (1)	11.657%	--	--	--	--	0.074	Inverted-U shape
Upper-Middle (2)	1.667%	-0.140%	--	--	--	0.072	Inverted-U shape
High (1)	-4.273%	--	--	--	--	0.054	U shape
High (2)	--	0.166%	--	--	--	--	--
World (1)	-1.105%	--	1.075%	1.425%	1.452%	0.039	U shape
World (2)	-1.068%	-0.029%	1.088%	1.466%	1.456%	0.039	U shape

Notes: GPP/GDP indicates the elasticity of GPP with respect to GDP_{ca}, while GPP/POP represents the elasticity of GPP_{psk} with respect to population (Pop). For each model, (1) and (2) in the first column refer to cases where the model was estimated without or with population, respectively. The turning point is calculated by the second derivative holding population constant for the equation with one.

Appendix

Table A1. GDP and GPP Growth Rates of Lower-Income Countries: 1982-2011

Low-Income Countries				*Lower-Middle-Income Countries*			
Country	ID	GDP	GPP	Country	ID	GDP	GPP
Mozambique	MZ	121.59	-3.78	Bhutan	BT	240.19	1.81
Uganda	UG	94.55	1.87	Vietnam	VN	187.76	1.61
Chad	TD	77.61	8.97	India	IN	163.78	29.88
Liberia	LR	75.26	0.32	Cambodia	KH	161.82	-1.33
Burkina Faso	BF	57.36	14.42	Laos	LA	134.78	-1.41
Mali	ML	56.32	11.21	Sri Lanka	LK	132.79	3.28
Rwanda	RW	31.98	2.26	Indonesia	ID	124.97	0.61
Burundi	BI	28.44	3.41	Egypt	EG	124.15	5.38
Syria	SY	21.62	5.47	Lebanon	LB	116.21	18.06
Malawi	MW	19.04	-4.72	Bangladesh	BD	102.23	9.39
Guinea	GN	10.33	1.82	Mongolia	MN	94.42	12.96
Zambia	ZM	5.69	-1.62	Lesotho	LS	87.85	-1.63
Guinea-Bissau	GW	0.55	8.18	Angola	AO	85.21	1.20
Congo DRC	CD	-8.35	-0.31	Tunisia	TN	81.21	59.57
Afghanistan	AF	-8.61	0.71	Ghana	GH	78.00	3.80
Gambia	GM	-10.71	14.29	Nepal	NP	75.09	5.67
Sierra Leone	SL	-14.35	0.50	Nigeria	NG	74.05	2.17
C. African Republic	CF	-17.86	2.18	Morocco	MA	73.18	32.25
Togo	TG	-18.54	4.59	Pakistan	PK	64.50	61.79
Madagascar	MG	-21.45	-1.17	Tanzania	TZ	60.89	-2.50
North Korea	KP	-31.62	-5.66	El Salvador	SV	60.12	2.03
Niger	NE	-32.20	6.90	Iran	IR	59.95	13.71
Somalia	SO	-33.07	-12.49	Swaziland	SZ	48.06	0.34
				Vanuatu	VU	45.06	-0.02
				Pap Guinea	PG	39.50	1.21
				S. Islands	SB	33.74	0.14
				Honduras	HN	31.97	-0.35
				Philippines	PH	30.42	0.62
				Bolivia	BO	28.51	-1.53
				Zimbabwe	ZW	20.48	-2.48
				Algeria	DZ	20.00	35.42
				Mauritania	MR	18.20	7.05
				Benin	BJ	17.20	4.41
				Kenya	KE	12.23	-5.45
				Senegal	SN	9.35	27.31
				Nicaragua	NI	5.58	0.17
				Djibouti	DJ	2.82	5.09
				Cameroon	CM	-21.17	2.48
				Haiti	HT	-44.06	5.14

Table A2. GDP and GPP Growth Rates of Higher-Income Countries: 1982-2011

Upper-Middle Income Countries				*High-Income Countries*			
Country	ID	GDP	GPP	Country	ID	GDP	GPP
Equatorial Guinea	GQ	826.77	0.34	South Korea	KR	230.53	-5.08
China	CN	399.22	8.79	Chile	CL	126.42	1.82
Botswana	BW	166.88	29.20	Ireland	IE	122.27	1.22
Thailand	TH	161.29	2.56	Poland	PL	106.44	2.29
Albania	AL	124.32	19.26	Cyprus	CY	93.88	12.80
St. Vincent & the Gre.	VC	119.94	2.43	Panama	PA	92.17	0.12
Malaysia	MY	112.25	0.09	Uruguay	UY	79.58	-9.83
Iraq	IQ	99.90	-8.15	Trin. and Tobago	TT	77.82	0.63
Dominican Republic	DO	97.81	2.46	Australia	AU	65.50	32.93
Turkey (Türkiye)	TR	91.64	25.09	Finland	FI	65.06	11.21
Costa Rica	CR	75.15	0.34	United Kingdom	GB	64.93	2.31
Belize	BZ	74.85	-0.84	Norway	NO	64.91	5.57
Argentina	AR	68.24	-9.35	Portugal	PT	64.89	4.12
Bulgaria	BG	67.53	16.07	Israel	IL	64.52	11.69
Guyana	GY	62.59	0.75	Spain	ES	63.10	10.45
Colombia	CO	57.58	1.09	Netherlands	NL	61.31	0.65
Cuba	CU	55.76	3.39	United States	US	60.50	-1.51
Peru	PE	55.62	0.38	Romania	RO	59.95	8.77
Brazil	BR	43.71	2.16	Austria	AT	59.39	3.57
Suriname	SR	38.56	0.08	Sweden	SE	57.34	7.64
Paraguay	PY	30.31	-3.23	Japan	JP	56.70	-2.73
Ecuador	EC	29.81	0.41	Germany	DE	55.94	-0.20
Namibia	NA	27.99	54.92	Canada	CA	51.20	6.54
Jamaica	JM	23.87	2.08	Oman	OM	50.99	3.34
Jordan	JO	21.97	0.52	Iceland	IS	48.75	7.17
Guatemala	GT	21.24	-0.44	Denmark	DK	48.61	-0.27
Mexico	MX	19.54	-3.18	Greenland	GL	48.15	23.60
South Africa	ZA	11.23	17.47	Hungary	HU	43.28	2.90
Venezuela	VE	5.88	5.92	France	FR	43.23	0.05
Gabon	GA	-24.48	0.35	New Zealand	NZ	41.27	3.32
Libya	LY	-79.83	3.68	Qatar	QA	40.41	7.23
				Italy	IT	40.13	6.54
				Switzerland	CH	34.49	3.64
				Greece	GR	32.33	12.61
				The Bahamas	BS	18.92	0.25
				Saudi Arabia	SA	7.89	8.58
				Brunei	BN	-34.50	0.29
				U. Arab Emirates	AE	-76.25	10.58