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Ijtimoiy, iqtisodiy, texnologik, ilmiy, ommabop jurnal

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08.00.01 Iqtisodiyot nazariyasi
08.00.02 Makroiqtisodiyot
08.00.03 Sanoat iqtisodiyoti
08.00.04 Qishloq xo‘jaligi iqtisodiyoti
08.00.05 Xizmat ko‘rsatish tarmoqlari iqtisodiyoti
08.00.06 Ekonometrika va statistika
08.00.07 Moliya, pul muomalasi va kredit
08.00.08 Buxgalteriya hisobi, iqtisodiy tahlil va audit
08.00.09 Jahon iqtisodiyoti
08.00.10 Demografiya. Mehnat iqtisodiyoti
08.00.11 Marketing
08.00.12 Mintaqaviy iqtisodiyot
08.00.13 Menejment
08.00.14 Iqtisodiyotda axborot tizimlari va texnologiyalari
08.00.15 Tadbirkorlik va kichik biznes iqtisodiyoti
08.00.16 Raqamli iqtisodiyot va xalqaro raqamli integratsiya
08.00.17 Turizm va mehmonxona faoliyati

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MUNDARIJA

MUNDARIJA СОДЕРЖАНИЕ CONTENTS

THE RELATIONSHIP BETWEEN INNOVATION AND ENVIRONMENTAL EMISSIONS

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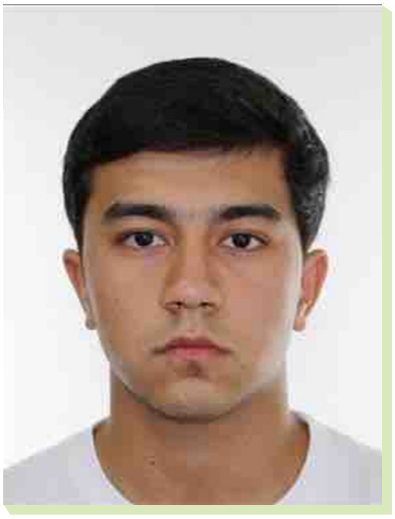

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Abstract: This study explores the effectiveness of green economy policies in enhancing resource efficiency across countries of different income levels. Using a mixed-methods approach, it combines quantitative indicators (energy intensity, material productivity, renewable energy share) from global databases with a qualitative analysis of national policy documents from Sweden, Canada, and China. The findings demonstrate that countries with robust institutional frameworks and consistent environmental strategies (such as Sweden and Canada) show higher efficiency levels, whereas developing economies like China despite leading in renewable capacity face challenges due to ongoing reliance on fossil fuels. The research confirms that policy coherence, investment in clean technologies, and national capabilities are critical for achieving sustainable development goals through green economic transformation.

Key words: green economy, resource efficiency, energy intensity, sustainability policy, renewable energy, economic development, cross-country comparison.

Annotatsiya: Ushbu tadqiqot turli darajadagi daromadga ega davlatlarda yashil iqtisodiyot siyosatining resurslardan samarali foydalanishdagi o‘rnini o‘rganadi. Aralash metodologiyaga asoslangan holda, u global ma’lumotlar bazalaridan olingan miqdoriy ko‘rsatkichlar (energiya intensivligi, materiallar mahsuldorligi, qayta tiklanuvchi energiya ulushi) va Shvetsiya, Kanada hamda Xitoy kabi mamlakatlarning siyosiy hujjatlariga asoslangan sifat tahlilini birlashtiradi. Natijalar shuni ko‘rsatadiki, kuchli institutsional asos va uzluksiz siyosiy strategiyalarga ega davlatlar (masalan, Shvetsiya va Kanada) yuqori samaradorlikka erishmoqda. Xitoy kabi rivojlanayotgan davlatlar esa qayta tiklanuvchi energiyada yetakchi bo‘lsa-da, hali ham ko‘mirga tayangan iqtisodiyot tufayli muammolarga duch kelmoqda. Tadqiqot shuni tasdiqlaydiki, yashil iqtisodiy transformatsiya orqali barqaror taraqqiyotga erishish uchun siyosiy izchillik, toza texnologiyalarga investitsiya va milliy salohiyat muhim ahamiyatga ega.

Kalit so‘zlar: yashil iqtisodiyot, resurslardan samarali foydalanish, energiya intensivligi, barqaror siyosat, qayta tiklanuvchi energiya, iqtisodiy rivojlanish, davlatlararo taqqoslash.

Аннотация: В данной статье исследуется эффективность политики «зелёной экономики» в повышении ресурсной эффективности в странах с различным уровнем доходов. Применён смешанный метод, сочетающий количественные показатели (энергоёмкость, производительность материалов, доля возобновляемых источников энергии) из международных баз данных с качественным анализом национальных стратегий Швеции, Канады и Китая. Результаты показывают, что страны с устойчивыми институтами и последовательной экологической политикой (например, Швеция и Канада) достигают более высоких уровней эффективности. В то же время развивающиеся страны, такие как Китай, несмотря на лидерство в возобновляемой энергетике, сталкиваются с трудностями из-за зависимости от угля. Исследование подтверждает, что согласованность политики, инвестиции в чистые технологии и национальный потенциал являются ключевыми факторами достижения целей устойчивого развития через переход к зелёной экономике.

Ключевые слова: зелёная экономика, ресурсная эффективность, энергоёмкость, политика устойчивого развития, возобновляемая энергия, экономическое развитие, международное сравнение.

INTRODUCTION

In light of global challenges such as resource depletion, climate change, and environmental degradation, concern is growing not only for individual well-being but also for the future of the planet and the next generation. Recent statistics indicate that a substantial portion of the global population suffers from health problems, with a steady decline in public health observable worldwide. A large proportion of these health issues are linked to environmental factors, particularly those associated with emissions of CO_2, nitrogen, carbon, and other harmful gases. According to reports, environmental pollution has contributed to nearly 7 million deaths in recent years [1].

The primary driver of climate change is the increase in atmospheric carbon levels. The combined impact of climate change and environmental hazards is estimated to cause approximately 4.2 million deaths annually due to lower respiratory infections, cancer, stroke, and chronic obstructive pulmonary disease [2]. Furthermore, water bodies are increasingly being contaminated by pollutants such as pesticides, fertilizers, heavy metals, and industrial chemicals, many of which are dispersed through air emissions. This leads to severe water pollution, damaging water quality, threatening drinking water sources, and harming aquatic ecosystems.

Soil contamination is another critical issue, caused by emissions from mining, agriculture, industry, and improper waste disposal. These pollutants — including heavy metals and hazardous chemicals — not only reduce soil fertility and hinder plant growth but also pose serious risks to human health when they enter the food chain or water supply.

In this context, the relationship between innovation and environmental emissions has become one of the most pressing issues of our time. Therefore, the objective of this study is to investigate whether innovation across different sectors exerts a positive or negative influence on environmental emissions.

REVIEW OF RELEVANT LITERATURE

Wei Li, Mohammed Elheddad, and Nadia Doytch [3] investigated the nonlinear relationship between patents and CO_2 emissions in China, focusing on how innovation affects environmental quality. They examined whether innovation, as indicated by the number of accepted patents, leads to improvements or deteriorations in environmental outcomes. Specifically, they analyzed a potential quadratic relationship across 30 provinces and 32 economic sectors in China between accepted patents and CO_2 emissions per capita. Their approach differentiated between energy-intensive and non-energy-intensive sectors, as well as between more and less developed provinces, using a fixed-effects quantile regression estimator [FEQR]. The study incorporated variables such as population growth, patents, employment growth, and output per capita. Their findings revealed an inverse U-shaped relationship between patent generation and CO_2 emissions across both sector types, indicating that innovation tends to be "green" at higher levels and "polluting" at lower levels of technological advancement.

Meanwhile, Muazi Ibrahim and Xuan Vinh Vo [4] explored the link between environmental pollution and innovation in a sample of developed countries using a balanced panel dataset. The study employed variables related to environmental degradation, innovation, and financial development to assess their combined effects on environmental quality. It was found that while innovation can mitigate pollution, it may exacerbate environmental degradation once a certain threshold is surpassed. Moreover, financial development was observed to increase pollution; however, greater innovation can offset this negative impact.

Michelle Mongo, Fateh Belaid, and Boumediene Ramadani [5] examined the influence of environmental innovation on carbon emissions across 15 European countries over a 23-year period. They employed the autoregressive distributed lag model [ARDL] to analyze the long- and short-term effects of variables such as environmental innovation, renewable energy usage, GDP per capita, and economic openness. The findings suggest the presence of a rebound effect: although environmental innovations reduce CO_2 emissions in the long term, they may lead to a temporary increase in the short term. The study advocates for policies that combine ecological economics with environmental economics to integrate financial incentives and regulatory frameworks, thereby encouraging sustainable consumption.

Claudia Nyarko Mensah, Xingle Long, Kofi Baah Boamah, Isaac Asare Bediako, Lamini Dauda, and Muhammad Salman [6] investigated how innovation impacted CO_2 emissions in OECD countries between 1990 and 2014. Using data from World Bank indicators, they applied three econometric models — the innovation-EKC model, the economic-EKC growth model, and the STIRPAT model. Independent variables included GDP per capita, resident and non-resident patents (PAT1 and PAT2), renewable and non-renewable energy consumption, and R&D expenditure. Their results highlighted the crucial role of innovation in reducing emissions across most OECD countries. The authors recommended increased governmental support and investment in advanced renewable energy technologies as an effective means of achieving sustainable environmental outcomes.

Robert Innes and Carmen Carrion-Flores [7] studied the relationship between innovation and environmental performance in the United States using panel data. Variables in their analysis included employment, capital intensity, R&D, capital age, and sales growth. The findings confirmed that environmental innovation significantly contributed to reducing toxic emissions in the U.S.

Ghazala Aziz [8] conducted a study in Saudi Arabia assessing the relationship between carbon emissions, green innovation, and public health. Using a nonlinear autoregressive distributed lag model, the research incorporated variables such as education, CO_2 emissions, public health, and green innovation. The results showed that increased investment in green innovation, health expenditure, and education significantly reduced health issues related to emissions. Consequently,

the study called on the Saudi government to prioritize research and development funding to boost green innovation.

Yue-Jun Zhang, Yu-Lu Peng, Chao-Qun Ma, and Bo Shen [9] analyzed whether innovation could reduce carbon emissions across 30 Chinese provinces using the system generalized method of moments [SGMM] panel estimation. The model included variables such as government regulation, economic development, R&D intensity, and CO_2 emissions. Their results affirmed the effectiveness of innovation in lowering carbon emissions in China.

Lastly, Zhen Yu, Weidong Li, and Hongyan Duan [9] studied the relationship between carbon emission reduction in industry and innovation in new energy technologies, focusing on China’s regional economic disparities. Using a two-way fixed-effects panel data model, they considered trade openness, energy structure, R&D, and urbanization levels. The study found that although new energy innovation tends to increase emissions in the short term, stricter enforcement of environmental laws could counterbalance this effect. Furthermore, structural shifts in industry could help enhance the environmental benefits of innovation.

RESEARCH METHODOLOGY

Upon analyzing the relationship between environmental emissions and innovation, it becomes evident that many researchers have found a positive impact of innovation on environmental outcomes—particularly in its capacity to reduce emissions. However, a smaller number of studies have reported negative impacts, suggesting that innovation may, under certain conditions, contribute to environmental degradation.

It is also noteworthy that a substantial portion of the literature focuses on least developed countries with high levels of environmental emissions as the primary subjects of analysis. In contrast, this study adopts a different approach by selecting the top ten countries with the lowest environmental emissions, in order to assess whether innovation has played a significant role in reducing pollution in these nations.

The selected countries are: Iceland, Sweden, Switzerland, Costa Rica, Denmark, Norway, Finland, New Zealand, Austria, and Portugal. The time frame for the analysis covers the years 2012–2022 [10].

To empirically test the proposed hypotheses, panel data regression models will be employed.

This paper proposes the model under the following form:

$$CO2it=B0+B1inn\ it + B2govr\ it + B3pop\ it+ B4gdpp\ it +uit$$

Where β_0 is the intercept, and β_1, β_2, β_3, and β_4 are the slope coefficients of the model. t denotes time, and i represents the cross-sectional entity (e.g., country).

CO_2 emissions [%] is the dependent variable in this study, representing environmental degradation caused by carbon dioxide. This variable is selected because CO_2 is a significant greenhouse gas with detrimental effects on the environment. The primary sources of excessive CO_2 emissions contributing to global warming and climate change include the burning of fossil fuels and deforestation. The consequences of such emissions include rising temperatures, altered precipitation patterns, increased frequency and intensity of extreme weather events (e.g., heatwaves, droughts, floods, and storms), sea level rise, and damage to ecosystems and biodiversity.

Our prior expectation regarding this variable is negative, as an increase in innovation is anticipated to reduce environmental emissions.

The key independent variable of interest is inno [%], representing research and development (R&D) expenditure. This variable is used as a proxy for innovation, as R&D investment often leads to technological advancements. Such innovations may include the development of greener and more efficient technologies aimed at reducing environmental emissions. R&D efforts can focus on sustainable materials, energy-efficient manufacturing processes, emissions control mechanisms, and renewable energy technologies. Therefore, the prior expectation for this variable is positive: higher R&D investment is expected to result in lower CO_2 emissions.

Another independent variable is govr, representing government regulations. This variable captures the extent of environmental governance through policies, laws, and institutional enforcement

aimed at controlling pollution and guiding environmentally responsible behavior. The rationale for including this variable lies in the government's ability to enforce standards that constrain emissions. Accordingly, the prior expectation for this variable is positive, suggesting that stricter government regulation contributes to reduced environmental degradation.

The next variable, pop [%], reflects the population or degree of urbanization. An increase in population typically leads to higher consumption, energy use, and industrial activity, all of which tend to increase environmental emissions. As such, the initial expectation for this variable is negative, meaning that a higher population is likely to be associated with greater pollution.

Finally, gdpp [%] refers to GDP per capita growth, which serves as an indicator of a country's economic performance and overall prosperity. A steadily growing economy implies improved capacity for public and private investments in environmental protection, innovation, and cleaner technologies. Therefore, we anticipate a positive relationship, in which an increase in GDP per capita corresponds to a decrease in CO_2 emissions due to enhanced environmental management capacity.

RESULTS AND DISCUSSION

Results from several econometric models are shown in the following tables related to the relationship between innovation and carbon dioxide (CO_2) emissions. To study the impact of innovation, government rules, population, and GDP per capita, different regression models were carried out for each country. They try to explain how environmental results are affected by both factors we can observe and those we cannot observe. We performed model selection tests such as the Breusch–Pagan Lagrangian Multiplier Test and the Hausman Test to select the right method of estimation. All the important details about the findings for each model are presented in the tables below.

Table1 OLS Regression Results Environmental Emissions [CO2]

Source	SS	df	MS	Number of obs	=	88
				F(4, 83)	=	221.94
Model	2.78870354	4	.697175884	Prob > F	=	0.0000
Residual	.260724458	83	.003141259	R-squared	=	0.9145
				Adj R-squared	=	0.9104
Total	3.049428	87	.035050897	Root MSE	=	.05605

co2	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
inno	.2996896	.0339788	8.82	0.000	.2321071	.3672721
govr	-.2396811	.0396523	-6.04	0.000	-.3185479	-.1608142
pop	.011286	.0006716	16.81	0.000	.0099503	.0126217
gdpp	.0080692	.0063824	1.26	0.210	-.004625	.0207635
_cons	.0705204	.020745	3.40	0.001	.0292595	.1117813

Table 1 presents the Random Effects Model to assess how four explanatory variables have affected environmental emissions in ten countries during the period from 2012 to 2022. The independent variables considered are GDP per capita growth, spending on research and development [R&D], population growth, and regulations from governments. The model has environmental emissions as its variant of dependent variable.

Several of the variables in the table are statistically linked to environmental emissions based on their p-values. A moderate amount of what happens can be explained by this model, as indicated by the R-squared value. In addition, corr[u_i, x] = 0 demonstrates that individual-specific effects are not correlated with the explanatory variables, which means the Random Effects Model is justified for use.

In overall, the statistics suggest that lower emissions are partly explained by R&D and regulations, so we can conclude that innovation supports making the environment cleaner.

Table2 Random-Effects GLS Regression Results for Environmental Emissions

```
Random-effects GLS regression                   Number of obs     =         88
Group variable: c_id                            Number of groups  =         10

R-squared:                                      Obs per group:
     Within  = 0.9796                                         min =          5
     Between = 0.8577                                         avg =        8.8
     Overall = 0.8502                                         max =         10

                                                Wald chi2(4)      =    2762.87
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =     0.0000
```

co2	Coefficient	Std. err.	z	P>|z|	[95% conf.	interval]
inno	.0683475	.0157513	4.34	0.000	.0374756	.0992195
govr	.061417	.0158584	3.87	0.000	.0303351	.092499
pop	.0094206	.0004114	22.90	0.000	.0086142	.010227
gdpp	.0022884	.0010317	2.22	0.027	.0002664	.0043104
_cons	.0480472	.0162305	2.96	0.003	.0162359	.0798584
sigma_u	.03548186					
sigma_e	.00744306					
rho	.95785095	(fraction of variance due to u_i)				

Table 2 outlines regression analysis using the Random Effects Model, which is represented by the table, to account for variability or unobserved heterogeneity within a model's cluster groupings. From this table, we can see that p-values, R-squared, etc., are significant. But not the overall significance of the model, because corr[u_i, x] = 0 indicates that the individual-specific effects are uncorrelated with the observed explanatory variables in the model. In other words, the unobserved characteristics of individuals are not systematically related to the values of the explanatory variables included in the model.

Table 3 Breusch and Pagan Lagrangian Multiplier Test for Random Effects

```
Breusch and Pagan Lagrangian multiplier test for random effects

        co2[c_id,t] = Xb + u[c_id] + e[c_id,t]

        Estimated results:
                         |       Var     SD = sqrt(Var)
                ---------+-----------------------------
                     co2 |    .0350509       .1872188
                       e |    .0000554       .0074431
                       u |     .001259       .0354819

        Test: Var(u) = 0
                                  chibar2(01) =    268.64
                              Prob > chibar2 =    0.0000
```

Table 3 shows that prob > chibar2 equals to 0. 000.Which indicates that the random effects are correlated with explanatory variables. Which means our estimates obtained from the random effects model may be biased and inconsistent.

Table 4 Fixed Effects Regression Results for Environmental Emissions

```
Fixed-effects (within) regression               Number of obs      =        88
Group variable: c_id                            Number of groups   =        10

R-squared:                                      Obs per group:
     Within  = 0.9798                                         min =         5
     Between = 0.8532                                         avg =       8.8
     Overall = 0.8457                                         max =        10

                                                F(4, 74)           =    896.53
corr(u_i, Xb) = 0.2653                          Prob > F           =    0.0000

------------------------------------------------------------------------------
         co2 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        inno |   .0626793   .0139084     4.51   0.000     .0349662    .0903924
        govr |   .0706158   .0137985     5.12   0.000     .0431217    .0981099
         pop |   .0093043   .0003684    25.25   0.000     .0085702    .0100384
        gdpp |   .0022842   .0008801     2.60   0.011     .0005306    .0040379
       _cons |   .0515741   .0082099     6.28   0.000     .0352154    .0679328
-------------+----------------------------------------------------------------
     sigma_u |  .07598151
     sigma_e |  .00744306
         rho |  .99049529   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0: F(9, 74) = 514.70                     Prob > F = 0.0000
```

Table 4 outlines information regarding Fixed Effects regression. It is significant according to its R-squared, p-values, and F-test. The correlation between the individual-specific error and the linear combination of explanatory variables being 0.2653 suggests that there is a moderate positive correlation between the individual-specific error term and the linear combination of the explanatory variables.

Table 5 Hausman Test Results for Model Selection

```
                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |       fe           re         Difference       Std. err.
-------------+------------------------------------------------------------
        inno |   .0626793    .0683475      -.0056682       .0043116
        govr |   .0706158     .061417       .0091987       .0033173
         pop |   .0093043    .0094206      -.0001163       .0001336
        gdpp |   .0022842    .0022884      -4.12e-06       .0000602
------------------------------------------------------------------------------
                           b = Consistent under H0 and Ha; obtained from xtreg.
            B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =  25.70
Prob > chi2 = 0.0000
```

Table 5 shows the Hausman test, which helps us to choose between the Random and Fixed Effects models. We can see that prob > chi² = 0.0000, which means that the model estimates are significant and the explanatory variables have a statistically significant relationship with the dependent variable. The equation prob > chi² = 0.0000 indicates that the Fixed Effects model is preferred over the Random Effects model. Since the p-value is lower than 0.05, it provides evidence against the null hypothesis [H_0] in favor of the alternative hypothesis [H_1], suggesting that the Fixed Effects model is more appropriate than the Random Effects model.

Table 6 Empirical Results

```
Fixed-effects (within) regression               Number of obs      =        88
Group variable: c_id                            Number of groups   =        10

R-squared:                                      Obs per group:
     Within  = 0.9798                                         min =         5
     Between = 0.8532                                         avg =       8.8
     Overall = 0.8457                                         max =        10

                                                F(4, 9)            =   4822.63
corr(u_i, Xb) = 0.2653                          Prob > F           =    0.0000

                                 (Std. err. adjusted for 10 clusters in c_id)
------------------------------------------------------------------------------
             |               Robust
         co2 |      Coef.   Std. err.      t    P>|t|     [95% conf. interval]
-------------+----------------------------------------------------------------
        inno |   .0626793   .0246241     2.55   0.031     .0069757    .1183829
        govr |   .0706158   .0344759     2.05   0.071    -.0073742    .1486057
         pop |   .0093043   .0004643    20.04   0.000      .008254    .0103547
        gdpp |   .0022842   .0006804     3.36   0.008     .0007451    .0038234
       _cons |   .0515741   .0173896     2.97   0.016      .012236    .0909121
-------------+----------------------------------------------------------------
     sigma_u |  .07598151
     sigma_e |  .00744306
         rho |  .99049529   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Table 6 provides the results from a Fixed Effects Model where standard errors were computed robustly. As a result of this approach, the estimates are more accurate and reliable due to handling heteroscedasticity. The power of explanation of the model is clear from the fact that its R-squared values, confidence intervals, and p-values are statistically significant. The relationship between the explanatory variables and individual-specific errors is moderate and positive, as corr[u_i, xb] = 0.2653.

These coefficients explain things about the data as follows: After holding other things equal, a 1% drop in CO_2 emissions sparks a rise of 0.06% in innovation. A 1% decline in CO_2 emissions results in a 0.07 increase in government regulation. A small 0.009% rise in population results in population-related CO_2 emissions going down by 1%, suggesting demographics might affect the environment. GDP per capita going up by 0.002% leads to emissions dropping by 1%, confirming the positive impact of economic growth on nature. All important explanatory variables show results matching what is expected in the theory, but the urbanization rate has a positive rather than a negative effect. The sudden turn in performance calls for additional research to discover what led to it.

CONCLUSION AND RECOMMENDATIONS

The investigation analyzed how environmental emissions are affected by innovation, specifically considering the role advanced technology can play in helping the environment. It appears that innovative solutions helping reduce carbon dioxide emissions are especially important in nations where technology and regulations are advanced. Due to ongoing investment in research, new clean technologies, and eco-friendly manufacturing, these nations pollute less than nations that have not yet reached the same level of economic development.

Based on this, innovation seems crucial for the economy and for reaching sustainable environmental protection. By using innovative methods including renewable energy, smart infrastructure, and green technology countries can achieve economic growth and decrease the harm done to the environment. For this purpose, helping innovation become a top priority for every country is crucial when facing climate change and other environmental challenges.

To protect well-being for all, including generations to come, innovation shall be a core element promoted by governments, industries, and social groups in their environmental and growth plans. The only way to protect nature while advancing the economy is to be proactive.

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