

Article

How Do Energy Price, Density, and Gini Changes Explain Biodiversity Outcomes? The Empirical Case of the United States

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Abstract: Biodiversity is diminishing and will continue to do so in the coming decades as human-caused biodiversity changes occur in both the developed and developing worlds. Using data from the United States of America for a cross-section of 39 states in 2010, this study merged the aspects of energy economics and income inequality, aiming to explain biodiversity in the developed world and find that there are opposite effects at play. On the one hand, more energy density in a state has a biodiversity-diminishing impact, and higher energy prices protect biodiverse areas. On the other hand, the dynamics of income inequality have a surprising effect: the more unequal a state's income has become in recent decades, the more biodiverse land is being protected. Thus, the rise in inequality is associated with more biodiverse land. Finally, this article discussed the linkages with the existing literature and provided policy recommendations.

Keywords: energy consumption; biodiversity; energy transition; environmental economics; energy economics



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1. Introduction

Finding abundance in energy consumption is bringing about dire effects for the environment. The energy-driven development model is not delivering the expected development requirements [1]. Biodiversity loss is happening now. It is caused by human action and diminishes the future benefits that we can derive from nature [2]. This situation is precisely why we should examine what affects the biodiversity conserved in developed countries, which is led by environmental regulation. This research embarks on an investigation of the United States (US) due to data availability and examines the linkages of the three-legged sustainability model covering social, economic, and environmental factors, and more precisely, what effect the price of energy, macro-level energy density, and change in Gini index has on areas dedicated to the conservation of biodiversity?

Power sector transitions have been predicted to bring about positive socio-economic consequences in the short and medium term while inducing adverse effects in the long run [3]. Instead, the authors look at the pre-transition era of 2010, when solar and wind energy were still relatively expensive, and dissect the effects of energy consumption and price on biodiversity.

Ordinary least squares (OLS) estimation was used for 39 US states in 2010. It was found that (i) more energy-dense states have less biodiversity, (ii) more expensive energy is associated with a greater preservation of biodiversity, and (iii) the change in direction for

greater inequality is also associated with a greater preservation of biodiversity. The Gini index changes cause the most substantially observed effect.

The novelty of this research lies in the income inequality biodiversity-saving effect, which is surprising given the theoretical and empirical literature and the consensus that more equality brings about better environmental outcomes. Thus, this research has followed the recommendation of [4] and bridges the gap between policy goals such as social protection and environmental sustainability in our study.

Section 2 reviews the literature, followed by Section 3, which describes the data and methods. Section 4 presents the empirical model and results. Section 5 discusses the results, and Section 6 concludes this study.

2. Literature Review

The authors first set the stage by introducing the recent literature in the context of a developed country, looking at the biodiversity and energy linkage and then discussing income inequality and environmental outcomes in the United States and other developed countries.

2.1. Biodiversity and Ecology During Energy Transition

A strong feedback mechanism is found between global biodiversity attention on one hand and carbon emissions and climate policy uncertainty on the other [5]. That is to say, there is a close connection between climate and biodiversity. Moreover, global biodiversity attention is very sensitive to changes in carbon emissions and the world production industry [5]. These recent findings show that biodiversity, ecology, and energy are closely interconnected with policymaking in terms of both production and impact. The authors reviewed the impacts of different renewable energy pathways on ecosystems and highlighted the mechanisms and effects associated with each path and technology [6]. In their review, they re-established the logic of renewable energy expansion to deliver significant environmental and socio-economic benefits.

However, the interest lies in the energy effect, and the authors consider the pre-transition period and socio-economic impact. Thus, this paper further explores the recent literature regarding total energy consumption and biodiversity.

2.2. Energy and Biodiversity: Consumption and Its Effects

While the interlinkage between energy consumption and biodiversity is less explored, a bustling literature on energy consumption and environmental quality, in general, is found. There is a general agreement that energy consumption is the primary source of greenhouse emissions due to the high fossil share in the energy mix, energy consumption for industrialization, and energy demand for urbanization and farming processing [7,8]. It has also been acknowledged that biodiversity is primarily threatened by anthropogenic factors, such as land use change, climate, and biochemical cycles, as well as the introduction of species [2]. An approximate cause–effect pathway can be drawn from the two main biodiversity change drivers, and the energy consumption effects depicted in Figure 1.

In the US, the most biodiverse areas do not always have the lowest energy density, as shown in Figure 2. Indeed, the most biodiverse states, such as Hawaii (9.41% of the state is a natural park area), Alaska (9.1%), and California (7.49%), do not have the lowest energy density; Hawaii takes 23rd place in the most energy-dense state list, and Alaska comes 12th (see the Data section for sources).

The paper moves forward by looking at the recent trends in the US energy markets.

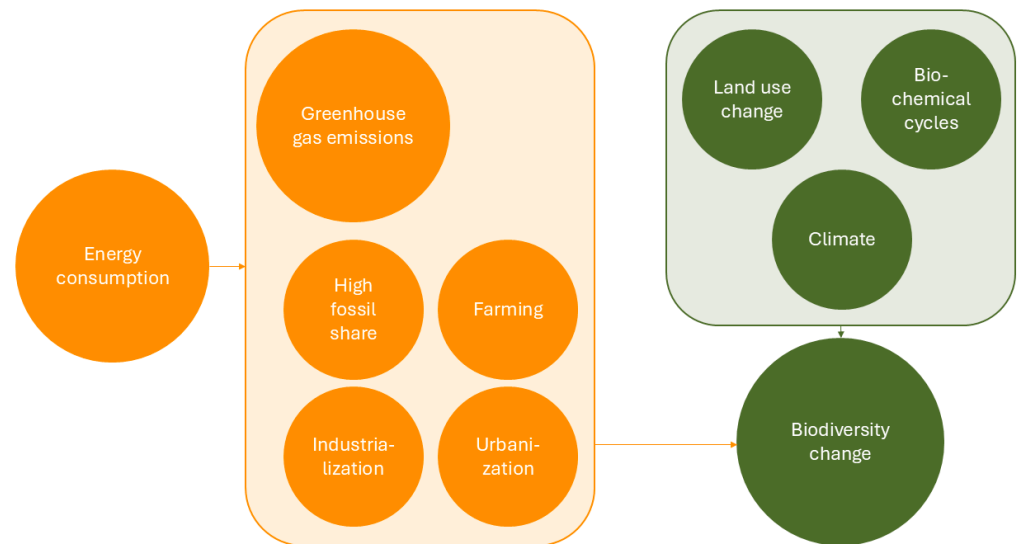


Figure 1. Energy consumption's effect on biodiversity: a framework.

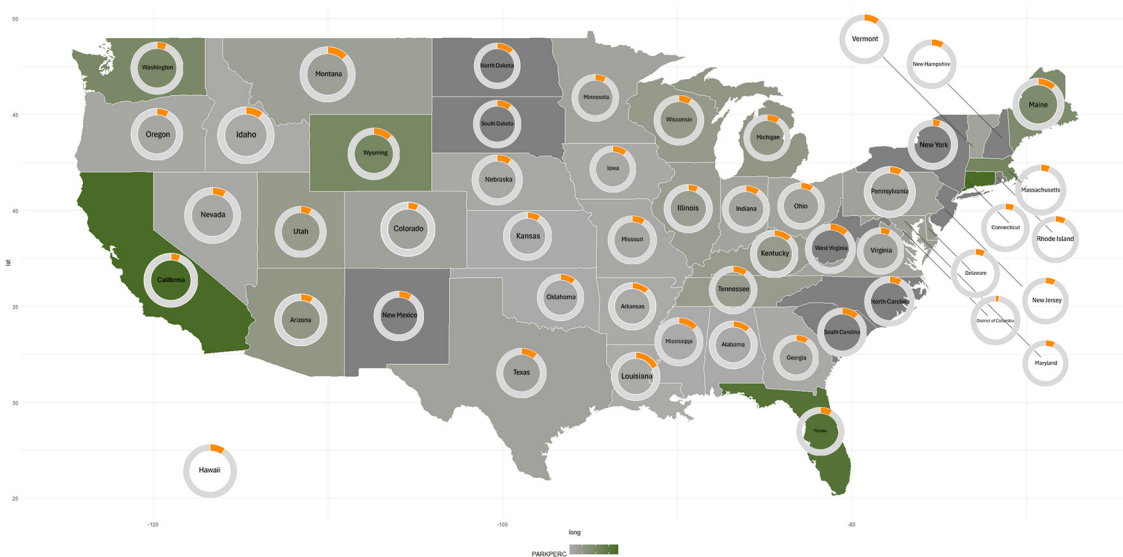


Figure 2. Biodiversity area density and energy density in the United States. Note: the greener the state is, the more biodiverse (higher nature park percentage of the total area) the state is. In circles, a share of energy expenditures of total state GDP is depicted. Source: author's work based on Khan et al. [9,10].

2.3. Energy Prices and Consumption in the US

It is a fact that energy demand is comparatively inelastic, but it also matters more than changes in other prices because energy prices experience increases at times atypical for other goods and services [11].

The authors suggest that higher energy expenditure and, therefore, more energy-dense industries like manufacturing, mining, and fossil fuel extraction contribute to environmental degradation, deforestation [12], and urban sprawl [13], which in turn, affects forest cover [14]. Indeed, in the USA, from 1970 to 2005, structural changes explain about 16–21% of aggregate energy intensity decrease [15,16]. At the same time, higher energy prices discourage excessive energy consumption, leading to reduced industrial activity [17] and lower resource extraction rates. Thus, expensive energy makes extractive industries less profitable and preserves ecosystems and biodiverse areas.

These general facts described above have shown that the US is the world's largest embodied energy importer (683 Mtoe) and embodied energy surplus receiver (290 Mtoe)

when considering all energy embodied in household consumption, government consumption, and investment [18]. Regarding total energy consumption and GDP growth in the US, it has been observed that the US economy is highly dependent on petroleum consumption: gasoline accounts for 48.7 per cent of all energy used by consumers and has the most volatile price, while it only accounts for 14% for producers [11]. Energy consumption in the industrial sector is key to economic growth and is highly sensitive to shocks [19].

Regarding energy prices, it has been observed that energy price increases cause recessions, yet decreases do not seem to cause expansions [11]. Regarding effects of prices on consumer expenditures, four complementary mechanisms have been observed: discretionary income effect, uncertainty effect, precautionary savings effect, and operating cost effect, all four implying a reduction in aggregate demand in the face of unanticipated energy price increases [11]. There may also be indirect effects at play, and some are referred to as the most significant and primary energy price–effect channel for the economy, related to patterns in consumption expenditures.

2.4. Income Inequality and Environmental Outcomes in the US

As [20] summarized, theoretical reasoning and empirical evidence support the hypothesis that greater inequality brings significant environmental harm. The study also mentioned that when beneficiaries from environmentally harmful activities exercise more power than those who bear the costs, more environmentally degrading activities result. However, partially enforcing this claim, [21] found that there is a non-linear relationship between the Gini index and income inequality. In particular, environmental health indicators show a non-linear relationship; whole ecosystem vitality indicators, notably terrestrial protected areas, have a more multifaceted set of influences [21] related to income inequality.

Indeed, the influence of income inequality on environmental quality is not univocal; greater equality may lead to lower environmental quality [22]. The result, in effect, depends on the political economy effect (the public choice approach whereby redistributing income affects society's demand for environmental quality and contributes to social harmony inducing long-term environmental investments) or the aggregation argument (whereby at the household level, income and environmental degradation find inverted-U shape relation, and aggregating would produce biased estimates) [22].

The authors of this study suggest that when inequality rises, biodiversity conservation arises because of a structural shift. Due to extreme inequality, there is less industrial expansion in highly unequal regions, indicating lower economic growth and reduced industrialization, which preserves natural biodiversity. When income inequality is rather extreme and there is a wealth concentration, wealthier elites may also push for environmental conservation at home while benefitting from resource exploitation elsewhere. Finally, in regions with high income inequality, state investments in industrial development may be lower, reducing pressure on biodiversity.

To summarize, energy consumption impacts greenhouse gas emissions via, in part, urbanization and farming, which also affect land use change and bio-chemical cycles that have their impacts on biodiversity change. The higher the energy price, the less energy is consumed (although it is deemed inelastic in general), and the less biodiversity change occurs. Regarding income inequality change, the more unequal the state becomes, the more urbanized it becomes, and the more biodiversity change occurs. Therefore, the authors examine the novel addition of Gini index change in conjunction with energy consumption and biodiversity change, which have already been explored. Now, the article proceeds to the empirical estimation of the model.

3. Data and Method

The investigation used the data available for the United States and, due to the limitations of data availability on social capital and income inequality indices, limited itself to investigating a cross-section of the year 2010 in 39 states (see Appendix A, Table A1, for the list of states included) of the United States. The data sources used are listed in Table 1.

Table 1. Data sources.

Variable	Full Name of the Variable	Units	Source
BIOD	Nature park area percentage from the total area of the state	Per cent	[9]
DENS	Energy expenditures as a per cent of current-dollar GDP	Per cent	[10]
PRICE	Price of electricity consumed	Dollars per Million Btu	[10]
GINI	Change in the Gini index between 1990 and 2010	Index	[23]

Table 2 provides summary statistics for the variables investigated. The most diverse descriptive terms are variables BIOD and GINI, whereas variables concerning energy, such as DENS and PRICE, are more condensed (see the column Std. Dev.).

Table 2. Summary statistics.

Variable	Obs.	Std. Dev.	Min	Max	Mean
BIOD	50	1.3236	−2.8134	2.2418	−0.0823
DENS	51	0.3165	0.8502	2.8870	2.1706
PRICE	51	0.4533	5.2679	8.0311	7.4570
GINI	40	1.1686	−10.1274	−3.1814	−4.4294

Note: All variables are in logs.

The distributions of variables are graphically depicted in Figure 3.

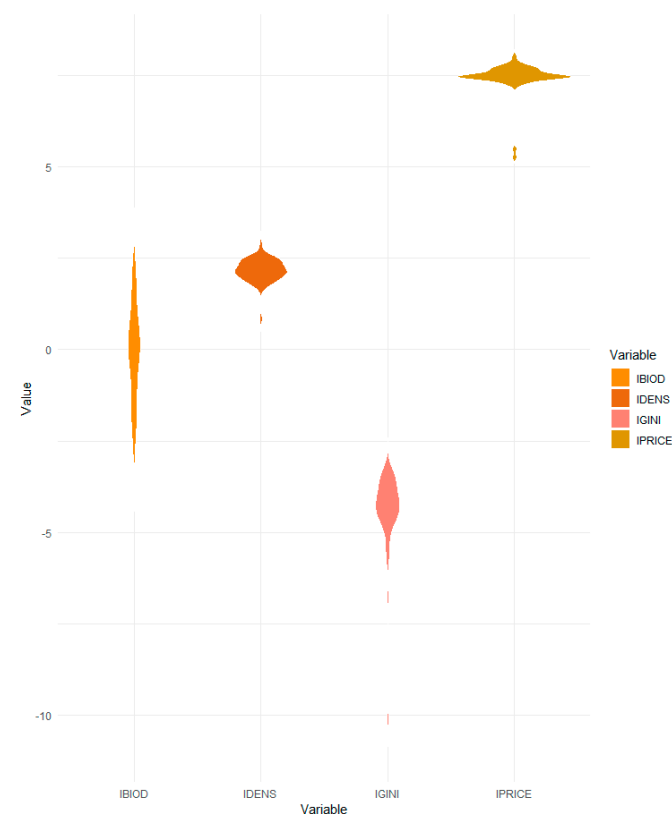


Figure 3. Distributions for variables in estimation.

Variables entering estimation (in logs) have low or medium correlation, which does not bias the estimates, as seen in Figure 4.



Figure 4. Correlation matrix for variables in estimation.

Next, empirical work and estimations are presented in Section 4.

4. Empirical Results

The estimates for the model are presented in Table 3. Biodiversity proxied by the percentage of the state territory being recognized as nature parks is explained by the state's energy density, price of energy, and change in the Gini coefficient, that is, changes in income inequality in the last two decades. One can easily recognize the opposite effects of energy density versus price and Gini changes on biodiversity. Indeed, the more energy-dense the state is defined by the energy expenditures as a per cent of current GDP, the less biodiversity there is. On the other hand, the opposite effect is observed with variables PRICE and GINI, where more expensive energy is associated with more preserved biodiversity, and the change in direction for greater inequality is associated with the same effect. The most substantial observed effect is caused by the Gini index changes, which reflects the social nature of the economic state of the region in question.

Table 3. Estimation results for biodiversity.

Variable	Coefficient	Robust Std. Err.
DENS	−1.6914 *	0.8372
PRICE	0.3582 *	0.2046
GINI	0.2635 **	0.1059
Const.	2.1291	2.6457
F	8.39	
Prob > F	0.0002	
R ²	0.2991	
Root MSE	1.0433	

Notes: ** and * denote statistically significant at 5% and 10%, respectively.

The model's explanatory and predictive power is relatively low yet acceptable when considering the social and related variables entering the model to a lesser extent. The results can be seen in Figure 5.

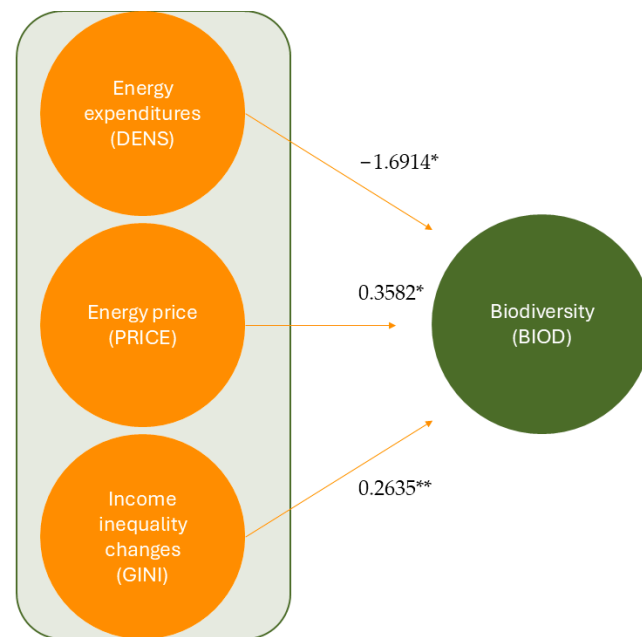


Figure 5. Results visualized. Notes: ** and * denote statistically significant at 5% and 10%, respectively.

Next, the paper discusses the results yielded in Table 3.

5. Discussion and Implications for Policy

In this study, biodiversity proxied by the state's protected area percentage was examined based on the energy density of the state, Gini index change, and electricity price. It is found that (i) more energy-dense states have less biodiversity, (ii) more expensive energy is associated with a greater preservation of biodiversity, and (iii) greater inequality is also associated with a greater preservation of biodiversity. The Gini index changes cause the most substantial observed effect.

The results reflect what has been discussed in the literature regarding energy consumption's detrimental effects on biodiversity. More expensive energy is most likely associated with less consumption, albeit energy is mainly inelastic, feeding into the impact of more preserved biodiversity. Lastly, and surprisingly, an increase in inequality is associated with a greater preservation of biodiversity. As far as the authors know, this last result is not yet documented in the literature.

As for the policy implications regarding energy density and expenditures and their negative relationship with biodiversity protection, stricter environmental regulations may be needed to regulate energy-intensive economic structures or provide incentives for cleaner technologies. As for energy prices, which have a positive relationship with biodiverse area conservation, carbon taxes or energy subsidy reductions could be suggested, making energy-intensive industries less attractive. Lastly, as for income inequality changes, we advise equitable and sustainable development with economic growth or degrowth to achieve biodiversity conservation and the well-being of society.

Regarding limitations, this study's cross-sectional nature is limited to the dissection of long-term effects. Indeed, this study would benefit from panel data availability, particularly for the income inequality variables. This circumstance implies that, with more data available, a more longitudinal study would be beneficial in dissecting the environment-energy-social nexus.

6. Conclusions

Biodiversity is changing and being lost and projected to be lost in decades, bringing dire consequences to economies. The authors hereby inquire whether energy density and prices can explain biodiversity outcomes in conjunction with income inequality changes.

A relatively focused study for a cross-section of 39 US states was conducted in 2010 using OLS. The findings revealed that (i) more energy-dense states have less biodiversity, (ii) more expensive energy is associated with more preserved biodiversity, and (iii) the change in direction for a greater inequality is also associated with more preserved biodiversity. This study highlights the need for further research into presumably diverse channels that affect income inequality change and biodiverse area conservation. These findings are especially relevant in the face of recent step-backs in environmental regulations in the US.

Regarding optimal biodiversity conservation in a developed country context, to protect the most valuable habitats, a balanced selection of social, economic, and natural elements should be considered [24]. However, sustainability shall also be reached considering the sharing economy and efficient resource utilization in the context of a highly developed country, ensuring the adoption of environmental patents and green technologies for long-term sustainability goal achievement, especially in the US [25].

This research concludes that more investigation should be conducted into presumably diverse channels that affect income inequality change and biodiverse area conservation to bring about novel results and further cement the channels through which inequality affects the environment. For example, the exploration of underlying causal mechanisms could be undertaken, such as the role of conservation policies in high inequality contexts or the influence of interest groups on environmental protection.

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Appendix A

Table A1. List of states included in this empirical investigation.

State	Abbreviation	State	Abbreviation
Alabama	AL	Nevada	NV
Arkansas	AR	New Hampshire	NH
California	CA	New Jersey	NJ
Colorado	CO	New Mexico	NM
Connecticut	CT	New York	NY
Delaware	DE	North Carolina	NC
District of Colombia	DC	North Dakota	ND
Florida	FL	Ohio	OH
Georgia	GA	Oregon	OR
Illinois	IL	Pennsylvania	PA
Indiana	IN	Rhode Island	RI
Iowa	IA	South Carolina	SC
Kansas	KS	South Dakota	SD
Maine	ME	Tennessee	TN
Maryland	MD	Utah	UH
Massachusetts	MA	Vermont	VT
Michigan	MI	Virginia	VA
Minnesota	MN	Washington	WA
Montana	MT	Wisconsin	WI
Nebraska	NE	Wyoming	WY

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