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Natural resource extraction - Sustainable development relationship and energy productivity moderation in resource-rich countries: A panel Bayesian regression analysis

Marco De Sisto [a], Shajara Ul-Durar [b,c,*], Noman Arshed [d], Mubasher Iqbal [e], Alireza Nazarian [f]

[a] *Graduate School of Business and Law, RMIT University, 445 Swanston Street, Melbourne, VIC, 3000, Australia*
[b] *University of Sunderland, The School of Business Management, Edinburgh Building, Chester Road, Sunderland, SR1 3SD, UK*
[c] *Durham University, Business School, Mill Hill Lane, Durham, DH1 3LB, UK*
[d] *Sunway University, Kuala Lumpur, Malaysia*
[e] *Department of Economics, The University of Lahore, Lahore, Pakistan*
[f] *University of Westminster, The School of Business Management, 35 Marylebone Road, NW1 5LS, UK*

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ABSTRACT

Social development is essential for improving quality of life, fostering stability, driving economic growth, achieving sustainable goals, enhancing human capital, encouraging civic engagement, building resilience, and fostering innovation, thereby ensuring inclusive, equitable, and sustainable progress. The Social Progress Index (SPI), also known as social development, contains all these features. This study aims to examine the impact of natural resource extraction on social development quadratically using data from 2011 to 2022. The focus of the study is on resource-rich countries. In this study, productive capacity in the energy sector is used as a social development determinant and a natural resource consumption moderator, ensuring sustainability in social development. Analyzing the quadratic relationship allows us to model and understand nonlinear relationships between the predictor and the outcome variable, capturing the effects that change direction or strength at different levels of the predictor. In this study, Bayesian regression is incorporated as an econometric approach. It provides more flexible modelling, incorporates prior knowledge, and offers a full distribution of parameter estimates, leading to better uncertainty quantification and more robust predictions. These estimates confirms a U-shaped natural resource extraction and social development relationship. Energy productive capacities in resource-rich countries not only enhance social development but also ensure the sustainable extraction of natural resources leading to sustainable social development. Population density and biodiversity are incorporated as control variables of the model. The impact of both is positive on social development.

1. Introduction

The term sustainability emerged when economic progress became the major source of social and environmental deterioration (Purvis et al., 2019). On one hand, there is a debate between quality and quantity with a perspective of population growth while, on the other hand, there is a clash of opinions on welfare economics and environmental economies which led researchers to explore ways to decouple economic progress from the environmental harm it produces (Shakoor and Ahmed, 2023). Fig. 1 shows the prevailing income dispersion across regions. It shows the variation of income distribution across different regions of the world. This indicates that the world necessitates sustainable development to spread the benefits to each country.

Sustainable development is crucial because it balances economic growth, environmental protection, and social equity, ensuring that the needs of the present are met without compromising the ability of future generations to meet their own needs (Kirkby et al., 2023). It comes under several Sustainable Development Goals (SDGs) (1–6 directly), while this study explores the role of goal 12 on sustainable development. Countries should focus on sustainable development to mitigate climate change, reduce poverty, promote health and well-being, and foster a resilient and inclusive global society (Asghar et al., 2024). For this, the

* Corresponding author. University of Sunderland, The School of Business Management, Edinburgh Building, Chester Road, Sunderland. SR1 3SD, UK.
E-mail addresses: marco.desisto@rmit.edu.au (M. De Sisto), Shajara.ul-durar@sunderland.ac.uk, Shajara.ul-durar@durham.ac.uk (S. Ul-Durar), nouman.arshed@gmail.pk (N. Arshed), mubasheriqbal88@gmail.com (M. Iqbal), Alireza.nazarian@mbacademy.org.uk (A. Nazarian).

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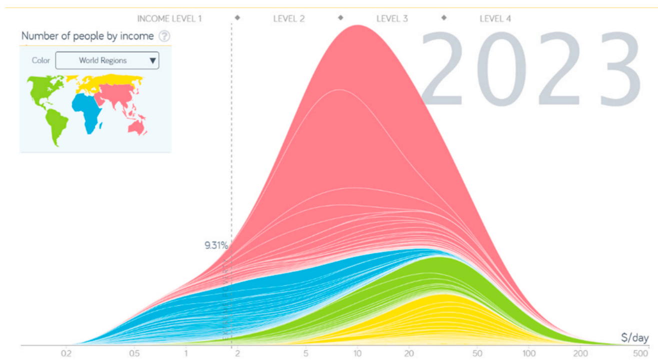

Fig. 1. Global income distribution (source: Gapminder visualization).

role of the United Nations Development Program (UNDP)[1] cannot be neglected because it plays a fundamental role in providing policy advice, technical support, and funding to help nations implement sustainable practices. Efforts of UNDP enable international cooperation between developed to developing countries. As a result, innovation and mobilizing resources to address complex global challenges are emerging, leading the countries toward sustainable development pathways (Sachs et al., 2022).

This study assumes natural resource extraction is crucial for sustainable development. Sustainable development is measured through the Social Progress Index (SPI) (Peiró-Palomino et al., 2024). This index is crucial as it enhances the well-being and quality of life for individuals and communities, promoting equitable access to resources, education, healthcare, and opportunities. It fosters social cohesion, reduces poverty and inequality, and empowers people to participate fully in society. By addressing social challenges and improving living standards, social development contributes to sustainable economic growth, stability, and overall societal progress (Vaskovskyi, 2020). While discussing natural resource extraction and development, one cannot ignore the well-known notion of "Dutch Disease." It describes how a country's sudden wealth from natural resources can harm its broader economy (Corden, 1984; Hardyal et al., 2024). The influx of foreign currency from resource exports strengthens the nation's currency, making other exports more expensive and less competitive. This can lead to a decline in manufacturing and agriculture resulting in economic imbalances and over-reliance on the resource sector. However, this study's focus is on resource-rich countries under this perspective with an exploration of the moderating role of energy efficiency.

Sustainable practices regarding natural resource extraction for resource-rich countries are crucial (Iqbal et al., 2024a). Natural resources are fuel to economic activities. When conducted responsibly, a successfully managed natural resource extraction system plays a crucial role in sustainable development (Hajad et al., 2023). When conducted non-responsibly, a natural resource extraction system leads to harmful sustainable development (Li et al., 2024). While talking about the positive impacts by utilizing the revenues from resource extraction, infrastructure, education, healthcare, and renewable energy, projects can be executed that can begin economic diversification and resilience. It will also lead to ensuring equitable distribution of these economic benefits which will help reduce poverty and improve social equity (Khan et al., 2024). As a result, sustainable development goals can be achieved (Alvarado et al., 2021). However, the dark side also exists. Natural resource extraction also impacts sustainable development by depleting resources, leading to environmental degradation like deforestation and pollution and, ultimately, contributing to climate change (Singh et al., 2024). At the same time, it drives employment opportunities and economic growth and often leads to community displacement, social inequalities, and conflicts. Economies reliant on natural resource extraction often face ups and downs due to market fluctuations (Vaskovskyi, 2020).

Sustainability in growth without efficient energy consumption cannot be imagined (Omer, 2008). It is the baseline assumption of this study that energy productive capacity assures sustainable development and moderate natural resource extraction (Zhao et al., 2024). The objective of adding a moderating effect is to ensure sustainable behavior of natural resource extraction (Marques et al., 2019) by efficiently using energy or heavily depending on renewable energy and lower greenhouse gas emissions (Adebayo and Ullah, 2023). In this study, energy productive capacity is incorporated as a natural resource extraction moderator (Boubaker and Omri, 2022). The use of a moderator can help extract variation in the theory that explains how independent variables influence dependent variables and also helps in handling heteroskedasticity (Haans et al., 2015). Energy productivity moderates in reducing reliance on natural resources, mitigates environmental degradation, and encourages natural habitat protection and ecosystems. As a result, sustainable development can be assured. Incorporating energy-efficient technologies and practices for households and industries lowers greenhouse gas emissions, enhancing the overall sustainability of energy systems (Mustafa et al., 2023).

After analyzing the functional relationship between natural resource extraction and sustainable development, along with the discussion of determining and moderating the energy productivity role for resource-rich countries, the study's objectives can be formulated. The key objective is to test the nonlinear impact of natural resource extraction and then to test the determining and moderating energy productivity role to test its direct impact on sustainable development and how it interacts with natural resource extraction. Population density and biodiversity are taken as the models' control variables in all of these scenarios. Lastly, to propose suitable policies for resource-rich countries is also included in the objectives of this study.

The study used the Bayesian Panel Fixed and Random Effect model to estimate the U-shaped effect of resource extraction on sustainable development. This model is superior because of its incorporation of prior information, handling of posterior uncertainty, and advanced model fit evaluation. The estimation results showed that the initial level of resource extraction is harmful to social development while energy productivity has shown positive moderation. After these introductory remarks, this study is divided into several other parts. The second part is a review of the literature. It analyzes the work done so far and identifies a literature gap that this study is designed to fill. The third part concerns data collection, the theoretical model, and the research methods. The fourth section discusses estimated results and their interpretations. Lastly, section five has some concluding remarks along with policy implications.

2. Review of the literature

Sustainable development holistically measures quality of growth while considering environment, society and posterity. An organizations central to this concept is the United Nations with its Sustainable Development Goals (SDGs) proposing a framework to address environmental and social challenges. The urgency of SDGs is higher in resource-rich countries which are reliant on resource extraction for development. This interaction requires critical policymaker insights for a balanced and resilient future.

Social development, as a component of sustainable development, is a widespread topic and many studies have covered it in the literature in several ways. While considering some baseline studies on the subject matter, Lélé (1991), Hall and Vredenburg (2004), Parris and Kates (2003), Redclift (2005), Sneddon et al. (2006), and Jabareen (2006) are prominent in the literature. These studies have analyzed sustainable development from their point of view. This study has taken it through

[1] United Nations, Department of Economic and Social Affairs - Sustainable Development Goals (SDGs) https://sdgs.un.org/goals.

social development. It comprehensively represents sustainable development by enhancing quality of life, reducing inequalities, and fostering inclusive growth which, together, support long-term economic prosperity and environmental sustainability.

The connection between sustainable development and natural resource extraction is solid. On this subject, Nijkamp et al. (1990), Tilton (1996), Wellmer and Becker-Platen (2002), Vittala et al. (2004), and Alfsen and Greaker (2007) are considered benchmark studies of this functional relationship. Many recent studies have tried to cover this matter comprehensively. As such, Manigandan et al. (2024), Liao et al. (2024), Singh et al. (2024), and Li et al. (2024) have confirmed the negative impact while Khan et al. (2023) and Leng et al. (2024) have confirmed a positive impact on sustainable development. Vaskovskyi (2020) has used the Social Progress Index (SPI) as a proxy for social development and confirmed the negative natural resource extraction impact. Studies also exist that have tested the nonlinear natural resources impact on sustainable development. In the nonlinear analysis, Liu et al. (2022), Iqbal et al. (2024a), and Wang et al. (2024) have validated that natural extraction initially promotes sustainable development but later on deteriorates it. On the other hand, Li et al. (2023) validate the opposite findings and confirmed that natural resource extraction initially deteriorates sustainable development but later on improves it.

The role of energy cannot be neglected for sustainable development. This is because energy efficiency reduces waste and maximizes the use of resources, energy consumption management ensures sustainable use, and renewable energy sources provide cleaner alternatives, all crucial for sustainable development by minimizing environmental and social impact and conserving resources for future generations. In this context, Zakari et al. (2022), Ofori et al. (2022), Adebayo and Ullah (2023), Anser et al. (2023), and Ozkan et al. (2024) have confirmed the favorable impacts of energy efficiency on sustainable development. Oppositely, Chen et al. (2024), Yan et al. (2024) and Liao et al. (2024) have confirmed the unfavorable energy efficiency impact on sustainable development. The literature is also evident regarding the moderating effect of energy efficiency for sustainable development. Thus, Shen et al. (2022), Boubaker and Omri (2022), Murshed et al. (2022), Akan (2023), Zhang et al. (2023), and Mustafa et al. (2023) have confirmed the moderating role of sustainable development highlights its significance for sustainable development.

Biodiversity is essential for sustainable development because it sustains ecosystems which, in turn, provide crucial services like clean air and water, climate regulation, and natural pest control (Arshed et al., 2024). It also supports agriculture, contributes to economic activities like tourism, and enhances resilience to environmental changes. However, a wide range of studies have discussed the significance of biodiversity for achieving sustainability. Many of them have acknowledged it for achieving sustainable development goals (Blicharska et al., 2019; Carvajal et al., 2021; Kumar et al., 2024; Opoku, 2019; Pouresmaieli et al., 2024; Saleh et al., 2024; Saliu et al., 2023). It could be said that biodiversity positively affects sustainable development. Influencing resource consumption, infrastructure, and emissions of greenhouse gases, speedy population growth severely affects sustainability (Dasgupta et al., 2023). Oppositely, low population density may hinder sustainability-harming factors (Imasiku and Ntagwirumugara, 2019; Maja and Ayano, 2021). A managed and well-controlled population growth is crucial to sustainable development. However, the literature is evident for both negative and positive impacts of population density. Studies including Ghanem (2016), Mondal (2019), Rehman et al. (2022), Xing et al. (2023), Kalim et al. (2023), Iqbal et al. (2023a, 2023b), and Li et al. (2024) have confirmed its responsibility for the deterioration in sustainable development. Studies such as those conducted by Chen et al. (2020), He et al. (2023), and Iqbal et al. (2024a) have validated this claim as it contributes to sustainable development. It implies that high population density can boost sustainable development by using resources better, encouraging new ideas, improving service access, and promoting social fairness as long as it is well-planned and governed.

Several studies have tried to significantly cover the subject of sustainable development but there is still a gap. The above-discussed studies have partially covered sustainable development by using different instruments like environmental quality indicators, poverty, and income inequality. However, this study has taken the SPI as an instrument for sustainable development that covers almost all SDGs. According to Beltrán-Esteve et al. (2023), Huang et al. (2023), Peiró-Palomino et al. (2024), and Kaminitz (2024) it offers a holistic measure of a country's social development, focusing on outcomes related to individual well-being across three dimensions: basic human needs, foundations of well-being, and opportunity. Unlike traditional economic indicators such as Gross Domestic Product (GDP), the SPI emphasizes equitable distribution of resources, environmental sustainability, and actual outcomes over inputs, aligning well with the United Nations' Sustainable Development Goals (SDGs). Its transparent, data-driven methodology provides actionable insights for policymakers, complementing economic indicators by highlighting how resources translate into social progress and thus providing a more accurate and meaningful measure of sustainable development. Vaskovskyi (2020) and Huang et al. (2023) used the same instrument as the dependent variable in a similar context, but its determinants are different from those in this study. Further, this study has specifically considered resource-rich countries using natural resource rent non-linearly with determining and moderating the role of energy productivity using advanced estimation methods.

A study conducted by Li et al. (2023) has tried to do similar work but they have used overall productivity which is based on eight different indicators. As a result, t is difficult to explain which indicator dominantly ensures sustainability. However, this study is more robust for the policy proposal aspect. This study used Bayesian regression which is different from ordinary least squares (OLS). However, Bayesian regression is often considered superior to OLS regression due to its ability to incorporate prior knowledge, manage uncertainty, and provide more robust estimates in the presence of small sample sizes or multicollinearity. Unlike OLS, which gives point estimates, Bayesian regression produces probability distributions for the estimated parameters offering a more comprehensive picture of parameter uncertainty (Chan et al., 2019; Greenberg, 2013). This approach allows for more flexible modeling, the inclusion of prior beliefs through prior distributions, and more accurate predictions, especially in complex or uncertain data environments (Geweke et al., 2011).

2.1. Theoretical model

To comprehend the theoretical relationship between natural

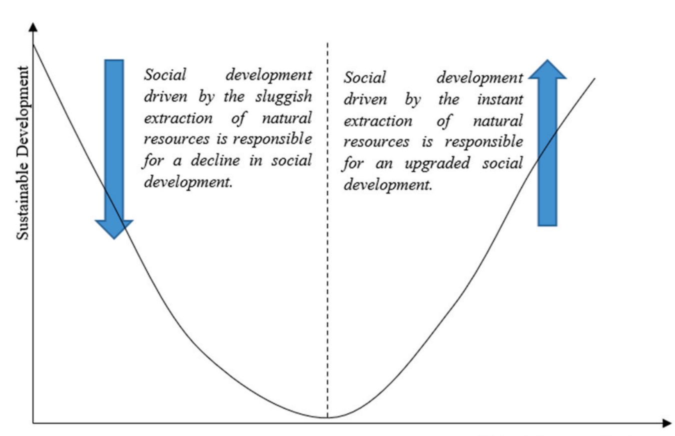

Fig. 2. Theoretical Model of nonlinear Impact.

resource extraction and its impact on sustainable development, Fig. 2 is a U-shaped curve that describes the nonlinear impact on sustainable development while Fig. 3 is a flowchart. This flow chart explains that there is a nonlinear effect of resource extraction on sustainable development while resource productivity moderates it. Initially, this study has assumed that natural resource extraction deteriorates sustainable development but later on is responsible to improve sustainable development (Li et al., 2023; Iqbal et al., 2024a), also denoted as environmental Kuznets curve (Nwani et al., 2023). This quadratic function implies that, initially, increased extraction leads to environmental degradation, social disruption, and economic instability thereby deteriorating sustainable development. This initial phase is characterized by overexploitation, pollution, and mismanagement of resources which undermine ecological balance and community well-being (Kwakwa, 2021). This relation led to proposing the first alternative hypothesis:

H1a. Resource extraction below the threshold has a negative effect on social development.

However, as resource extraction continues and economies develop, there is a transition point where increased wealth, technological advancements, and better governance practices lead to improved environmental standards, social equity, and economic stability (Veltmeyer, 2023). This results in a positive feedback loop where sustainable development is enhanced through more efficient resource use, investment in renewable technologies, and strengthened institutional frameworks. Therefore, analyzing the quadratic relationship allows one to model and understand nonlinear relationships between the predictor and the outcome variable, capturing the effects that change direction or strength at different levels of the predictor (Iqbal et al., 2024b). This led to proposing the second alternative hypothesis:

H2a. Resource extraction above the threshold has a positive effect on social development.

An increase in natural resource productive capacity can help improve social development in several ways. First is the increase in resource efficiency via which economic performance is improved and environmental impact is reduced (Li et al., 2023; Kirikkaleli and Ali, 2024). Higher productivity also improves economic stability because of fall in reliance on volatile resource markets (IEA, 2014).

This study incorporates energy productive capacity as a natural resource extraction moderator (Mustafa et al., 2023). As shown in Fig. 3, natural resource extraction affects sustainable development non-linearly but this impact can be moderated through energy productivity (Zia et al., 2021). Aligning with Zhang et al. (2023) this study assumes that an efficient energy-productive capacity can mitigate the adverse impacts of natural resource extraction, steering it towards sustainability by enhancing resource efficiency, reducing environmental degradation, and promoting economic and social stability. Thus, the moderating effect of resource efficiency would be observed as the shifting of a nonlinear curve (from Fig. 2) upward, leading to an overall increase in sustainable development at all levels of resource extraction (shown in Fig. 4). This effect is measured by using the cross product of the moderator and independent variable. This led to proposing the third alternative hypothesis:

H3a. Resource extraction and energy productive capacity have a positive effect on social development.

3. Sample size and research methods

3.1. Variables

This study has collected variables from some secondary sources from 2011 to 2022. This period is defined by data availability. This study's sampled countries are the top 19 resource-rich countries (Li et al., 2023). The country list is presented in Appendix 1. The dependent variable of this study is the Social Progress Index collected from the Social Progress Imperative (SPI, 2022). It is taken as the instrument of sustainable development. Further, energy productivity is considered a sustainable development determinant and the moderator of natural resource extraction, as collected from the United Nations Conference on Trade and Development (UNCTAD, 2021). It measures a country's access to and utilization of energy resources, essential for driving economic activities and sustainable development. Total natural resource rent is taken as natural resource extraction proxy while biodiversity and population density are taken as the control variables of the model. Total natural resource rent and population density are taken from World Development Indicators (WDI, 2021) and biodiversity is taken from the Environment Performance Index (EPI) (Wolf et al., 2022). Table 1 is constructed to explain the variables along with short definitions, symbols, and sources.

3.2. Econometric approach

This study is based on Bayesian regression and it incorporates prior knowledge with observed data to estimate the probability distributions of model parameters, offering robustness to small sample sizes and uncertainty quantification unlike OLS (Ordinary Least Squares) which provides point estimates without accounting for prior information (Slovic and Lichtenstein, 1971). This study has incorporated a panel data Bayesian regression. It accounts for individual heterogeneity and uncertainty in model parameters through probability distributions (Moral-Benito, 2012). This study has used it with random effect

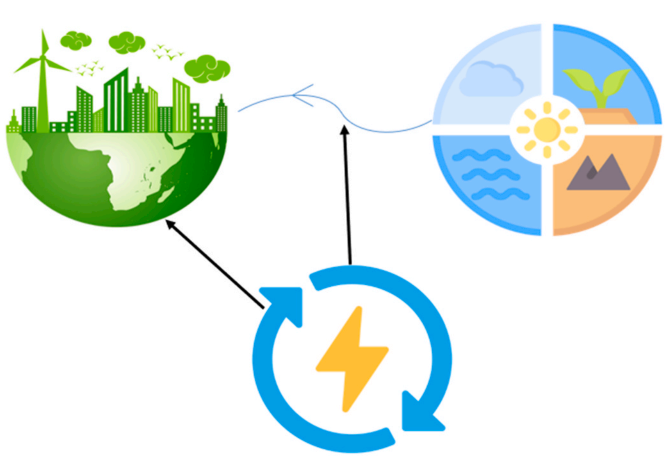

Fig. 3. Overall theoretical model.

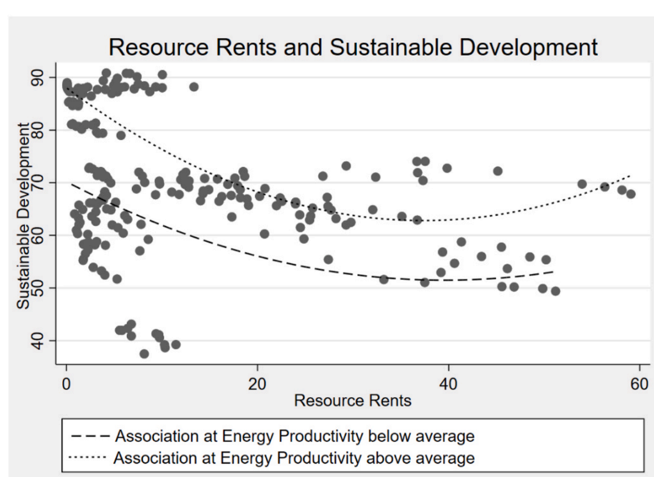

Fig. 4. Rents and social development association.

Table 1
Variables and their data sources.

Variables (Symbol)	Short Definitions	Source
Sustainable Development (SD)	Country's social and environmental well-being across basic needs, well-being foundations, and opportunities.	SPI (2022)
Natural Resources (NR)	The summation of oil, natural gas, coal, mineral, and forest rents.	WDI (2021)
Energy Efficiency (EN)	Maximizing output while minimizing energy consumption, ensuring effective use of energy resources.	(UNCTAD, 2021)
Population Density (PD)	The number of people living per unit of area.	WDI (2021)
Biodiversity (BD)	Diversity of life forms at various levels, including genetic diversity within species, diversity between species, and diversity of ecosystems. It is a sub-index of the Environment Performance Index (EPI) which is available in EPI reports.	Wolf et al. (2022)

specification which is provided by Bayes' panel data regression while manual estimation of fixed effect is done using the LSDV (Least Square Dummy Variable) method. Since both of the models are generated using different methods there is not direct comparison between them using the Hausman test. Hence, this study will compare the models using the average efficiency of the outcome. Here, Equations (1)–(7) are the baseline equations for its derivation. In Equation (1) y and x represent the dependent variable and independent variables respectively for i cross section and t time periods. Further, β is the regression coefficient and α is the overall intercept. u_i is the individual-specific random effect (random intercept) and ε_{it} is the error term. In Bayesian statistics, prior distributions represent initial beliefs about parameters before observing data which are the patterns in data observed using simple regression. There is a combined likelihood function representing this available data and its simple regression conditional distribution which led to the development of Bayes' based posterior distribution. This distribution shows the updated beliefs. Equations (2)–(5) are the priors related to Equation (1).

$$y_{it} = \alpha + \beta x_{it} + u_i + \varepsilon_{it} \tag{1}$$

$$\alpha \sim N\left(0, \sigma_\alpha^2\right) \tag{2}$$

(prior for the overall intercept)

$$\beta \sim N\left(0, \sigma_\beta^2\right) \tag{3}$$

(prior for the slope coefficient)

$$u_i \sim N\left(0, \sigma_u^2\right) \tag{4}$$

(prior for the random effects)

$$\varepsilon_{it} \sim N\left(0, \sigma_\varepsilon^2\right) \tag{5}$$

(prior for the error term).

The likelihood function in Bayesian regression with random effects encapsulates the probability of observing the data given the parameters of the model based on a conditional probability distribution. Equation (6) specifies this model using a Gaussian distribution 'N'. For panel data, the likelihood function differentiates between a cross-sectional random component and error term. With normal distribution assumption, this model enables the prediction of dependent variables. The Bayesian likelihood function is important for inferential analysis of updating beliefs leading to posterior distribution with random effects. Equation (7) represents the posterior distribution based on updated beliefs which provides the uncertainty linked with each parameter. It serves as the foundation for making inferences and drawing conclusions about the parameters of interest in the Bayesian framework (Gelman et al., 2008; Pennell et al., 2010; Shen et al., 2020; Xu et al., 2023).

$$P\left(y \middle| \alpha, \beta, u, \sigma_\varepsilon^2, x\right) = \prod_{i=1}^{N} \prod_{T=1}^{T} N\left(y_{it} \middle| \alpha + \beta x_{it} + u_i, \sigma_\varepsilon^2\right) \tag{6}$$

$$P\left(\alpha, \beta, \sigma_u^2, \sigma_\varepsilon^2 \middle| y, x\right) \propto P\left(y \middle| \alpha, \beta, u, \sigma_\varepsilon^2, x\right) \cdot P(\alpha) \cdot P(\beta) \cdot P\left(u \middle| \sigma_u^2\right) \cdot P\left(\sigma_u^2\right) \cdot P\left(\sigma_\varepsilon^2\right) \tag{7}$$

Based on these derivations of Bayesian regression, this study will estimate Equation (8) where the left-hand side shows the dependent variable and right-hand side is independent variables. This study has taken the Social Progress Index (SPI) as an instrument of sustainable development following studies like Beltrán-Esteve et al. (2023), Huang et al. (2023), Peiró-Palomino et al. (2024), and Kaminitz (2024). This study has incorporated the quadratic form of total natural resource rent to test the nonlinear impact, keeping in view the framework of Liu et al. (2022) and Wang et al. (2024). Energy efficiency is taken as an indicator of sustainable development and a natural resource rent moderator. Studies including Anser et al. (2023) and Ozkan et al. (2024) have tested its determining impact for sustainable development while Shen et al. (2022) and Akan (2023) have accounted it for moderating effect. Population density and biodiversity are taken as the control variables. Therefore, He et al. (2023) and Iqbal et al. (2024a) claim the significance of population density in determining sustainable development. In unison, Kumar et al. (2024), and Saleh et al. (2024) have highlighted biodiversity's importance for sustainable development.

$$SD_{it} = \beta_0 + \beta_1\, NR_{it} + \beta_2\, NR_{it}^2 + \beta_3\, EN_{it} + \beta_4\, NR{*}EN_{it} + \beta_5\, PD_{it} + \beta_6\, BD_{it} + \varepsilon_{it} \tag{8}$$

In the estimation of Equation (8), β_1 and β_2 explain the nonlinear effect of NR on SD which addressed the first part of the objective while β_3 and β_4 explain the moderating role of EN on the NR – SD relationship which addresses the second part of objectives.

4. Results

This section begins with the interpretation of Table 2. It contains descriptive aspects of all the variables of this study. First of all, there is a sample size. After that, mean and median present the central tendency measure. Next, there is a standard deviation (S.D) in the table showing a statistical measure that quantifies the amount of variation or dispersion in a set of data values. Skewness is showing that the Social Progress Index, energy productivity, and population density are negatively skewed while others are positively skewed. The kurtosis 3 shows no outliers in the data while kurtosis <3 means too few and >3 shows too many outliers in the data. The Social Progress Index, energy productivity, and population density have too few outliers and the other variables have too many outliers. Further, Table 3 shows the strength of association among the independent variables. No variable shows a high association. Thus, in this proposed functional form multicollinearity does not exist. Fig. 4 shows the nonlinear association pattern of natural resource rent and Social Progress Index with and without moderating effect of energy productive capacity. It shows a U-shaped association pattern with and without a moderating effect. When the average value of energy productive capacity is incorporated, the U-shaped relationship

Table 2
Data descriptives.

Stats	SD	NR	EN	PD	BD
N	228	228	228	228	228
Mean	70.238	12.418	35.772	50.762	101.120
Median	68.855	5.879	34.682	49.326	46.601
S.D	13.303	14.216	7.648	22.845	113.835
Skewness	−0.222	1.456	−0.110	−0.013	1.527
Kurtosis	2.471	4.223	2.447	2.356	5.140

Table 3
Correlation matrix.

	NR	EN	PD	BD
NR	1			
EN	−0.349	1		
PD	−0.283	0.508	1	
BD	0.023	−0.021	−0.204	1

has shifted upward indicating the significance of the moderating effect. This implies that when energy productive capacity moderates with natural resources the strength of the association between natural resources and sustainable development transforms into an innovative pattern.

The estimated results of the random effect model are presented in Table 4 and fixed effect model in Table 5. The comparison of both models shows that the marginal effects are similar in direction and significance in both models. Based on efficiency estimates which are 0.033 in random effect and 0.023 in fixed effect model which are above 0.01, it is concluded that the model is efficient and random effect model is superior. It contains the regression coefficients of Bayesian regression along with standard deviations of the coefficients and 90% credible interval. All the variables are significantly impacting the dependent variable. A U-shaped relationship between natural resource extraction and the Social Progress Index is validated. It implies that, initially, the extraction of natural resources diminishes sustainable development but later on improves (Li et al., 2023). The literature discusses both negative and positive impacts of natural resource extraction. However, Singh et al. (2024) and Li et al. (2024) confirmed the negative role while Khan et al. (2023) and Leng et al. (2024) have confirmed a positive impact on sustainable development. It implies that at low levels of extraction sustainable development is negatively impacted, likely due to insufficient economic growth and underutilization of available resources. As extraction intensifies, sustainable development initially declines, possibly because of environmental degradation, resource depletion, and social disruptions. However, beyond a certain threshold further increases in resource extraction led to improvements in sustainable development. This improvement may result from the implementation of more efficient extraction technologies, better regulatory frameworks, reinvestment of resource revenues into sustainable projects, and enhanced socio-economic conditions.

Estimated results have confirmed that energy productive capacity expands sustainable development and also moderates the natural resource extraction system for improved sustainable development. Following the study findings, the confirmation that energy efficiency enhances sustainable development and moderates the impact of natural resource extraction implies that improving energy productive capacity enhances energy efficiency which can significantly lower production costs, reduce environmental impact, and increase competitiveness. Economically, this means businesses face lower energy expenses which can lead to higher profitability and reinvestment in growth. Additionally, more efficient energy use can stimulate innovation and attract investment, ultimately fostering sustainable economic development. A small number of empirical studies like Ofori et al. (2022) and Ozkan et al. (2024) have supported the outcome of positive energy productivity effect on sustainable development. This productivity can mitigate energy dependency in production. It will help reduce resource extraction and expedite growth by reducing dependency and ensuring sustainable development. Energy efficiency reduces the need for raw materials and lowers environmental impact by optimizing resource use, thus promoting sustainability in natural resource extraction and assures optimization to achieve a sustainable future (Mustafa et al., 2023; Zhang et al., 2023).

Table 4
Bayesian panel random effect regression estimations.

Variables	Coeff.	S.D	90% Credible Interval	
NR	−0.568	0.143	−0.813	−0.342
NR2	0.001	0.0008	0.0001	0.002
EN	0.644	0.222	0.305	1.017
NR*EN	0.009	0.003	0.003	0.016
PD	0.043	0.011	0.025	0.060
BD	0.095	0.014	0.071	0.119
C	42.678	7.501	30.594	54.914
MCMC Sample	10000	Avg Efficiency	0.033	

Table 5
Bayesian panel fixed effect regression estimations.

Variables	Coeff.	S.D	90% Credible Interval	
NR	−0.635	0.025	−0.675	−0.593
NR2	0.002	0.0004	0.001	0.002
EN	0.323	0.012	0.304	0.343
NR*EN	0.012	0.001	0.011	0.013
PD	0.065	0.001	0.063	0.066
BD	0.087	0.004	0.079	0.094
C	70.657	0.081	70.524	70.790
MCMC Sample	10000	Avg Efficiency	0.023	

Fig. 5 is constructed to graphically validate the moderating effect. It is a 3D plot of the moderating effect to rigorously analyze energy productive capacity as a moderator constructed using MATLAB. The moderating effect in different quantiles of data shows that in resource-rich countries energy productive capacity is crucial in significantly lowering production costs, reducing environmental impact, and increasing competitiveness. From an economic perspective, this translates to businesses experiencing lower energy costs, ultimately leading to increased profits and the ability to reinvest in expansion.

Regarding the impact of control variables related to population density, the positive impact concludes that higher population density is often responsible for an efficient use of resources as well as improved public transportation systems and reduced per capita energy consumption due to shared services and facilities. Additionally, it encourages innovation and social interconnection, leading to sustainable development. This relationship highlights the potential for rural-to-urban migration and smart city planning to enhance sustainability. It also highlights the need for planned urbanization that maximizes the benefits of population density while addressing challenges (He et al., 2023; Iqbal et al., 2024a). The biodiversity's impact on sustainable development is also significantly positive. Biodiversity enhances ecosystem resilience, ensuring the stability of environmental services, such as clean water, fertile soil, and pollination, essential for human well-being and economic activities. The same is the thing pointed out by Pouresmaieli et al. (2024) and Saleh et al. (2024). It also contributes to climate regulation, disease control, and cultural values. Therefore, protecting and promoting biodiversity is crucial in order to reinforce sustainable development.

Figs. 6–12 in the appendix provides variable-wise post regression test showing the trace values for variability, histogram and density graph for normality, and column graph for autocorrelation. Here it can be seen

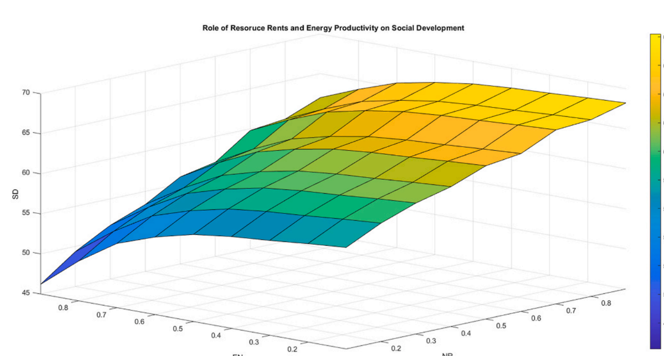

Fig. 5. Moderating effect at different percentile positions.

that for all variables there is no apparent pattern in trace, estimates are normal, and there is no incidence of significant autocorrelation.

5. Concluding remarks and policy recommendation

Considering the objectives of this study, estimated results through Bayesian regression have confirmed the U-shaped natural resource extraction and sustainable development relationship for resource-rich countries. The Social Progress Index is taken as an instrument for sustainable development. It implies that the initial impact of natural resource extraction on social development is negative but it ultimately leads to positive improvements. However, at the initial stages, extraction activities can lead to deterioration in every aspect of social setup such as environmental degradation, displacement of communities, and inequality. However, as extraction processes mature and governance improves, the wealth generated can be reinvested into social infrastructure, education, and healthcare, enhancing social development. This study used energy productive capacity or energy efficiency to moderate this relationship. Estimated results have validated that it expands social development and ensures sustainability in social development through natural resource moderation. In conclusion, the moderating role has confirmed sustainability. Population density and biodiversity as control variables of the model are validated as sustainable development activists.

The policy implications derived from these findings highlight the critical importance of energy efficiency and natural resource management for resource-rich countries. Firstly, these nations should prioritize substantial investments in advanced energy-efficient technologies and infrastructure to optimize energy use and reduce operational costs. Such investments not only enhance economic competitiveness but also contribute to sustainable development by mitigating the negative environmental impacts associated with energy consumption. In addition, implementing stringent environmental regulations is essential to curb the adverse social and ecological effects of resource extraction. Effective regulation helps to safeguard ecosystems and communities from the detrimental consequences of excessive or poorly managed resource extraction activities. Furthermore, governments must ensure that revenues generated from natural resource exploitation are transparently and effectively reinvested into social infrastructure. This involves channeling funds into critical sectors such as healthcare, education, and public services to promote inclusive growth and enhance the quality of life for all citizens. Investments in these areas not only address immediate social needs but also build a foundation for long-term economic stability and social equity.

Promoting sustainable natural resource extraction practices through targeted incentives and support for companies is another key policy measure. By encouraging firms to adopt environmentally friendly practices and demonstrating social responsibility, governments can mitigate environmental damage and foster a culture of sustainability within the private sector. Such measures are vital for ensuring that resource extraction contributes positively to both economic and environmental goals. Finally, strengthening governance and institutional frameworks is imperative for the effective and equitable management of resource wealth. Robust governance structures ensure that resource revenues are managed transparently and fairly, reducing the risk of corruption and ensuring that the benefits of resource wealth are distributed equitably among the population. By enhancing institutional capacity and promoting good governance practices, resource-rich countries can better manage their resource wealth, achieve sustainable development objectives, and ensure that the benefits of their natural resources contribute to broader societal well-being.

Population density and biodiversity are validated as significant drivers of social development that lead to sustainable development for resource-rich countries. Governments must prioritize urban planning and infrastructure development to accommodate higher population densities efficiently as it will pave the way for quality housing, transportation, and green spaces. Regarding the implementation of biodiversity requiring policies that establish protected areas, governments should encourage sustainable land use and support biodiversity-friendly practices in the agriculture and industry sectors. As time advances, governments should foster green job creation and economic opportunities while preserving biodiversity. Engagement of the communities and education initiatives should be prioritized. Governments should also ensure access to essential services such as healthcare, education, and social support in densely populated areas. Lastly, other aspects like water management, forestry practices, and ecosystem conservation should not be ignored.

The results of this study are limited to the sample of resource rich countries. Future research studies can explore different combinations of sub-indices of SPI and different forms of resource rents and productivity capacities other than natural resources in order to extensively elaborate how productivity with respect to the management of natural source extraction are leading to changes in social development.

Ethical approval

The entire research process is in line with our institutional research ethics policy. We declare that all ethical standards are met and complied with in true letter and spirit.

Informed consent

All participants in this study volunteered themselves during the entire research process, and their consent was taken at inception.

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CRediT authorship contribution statement

Marco De Sisto: Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Shajara Ul-Durar:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Noman Arshed:** Writing – original draft, Software, Formal analysis, Data curation. **Mubasher Iqbal:** Writing – original draft, Visualization, Validation. **Alireza Nazarian:** Writing – original draft, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Appendix 1

Australia	Niger
Brazil	Norway
Canada	Poland
China	Qatar
Germany	Russia
India	Saudi Arabia
Indonesia	South Africa
Iraq	United Arab Emirates
Kazakhstan	United States of America
Kuwait	

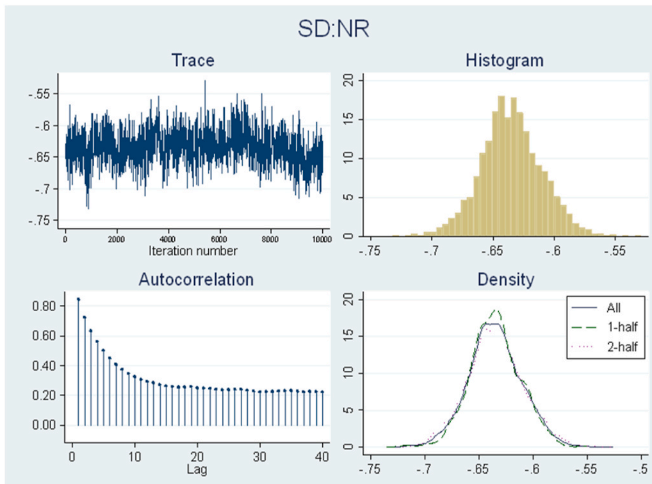

Fig. 6. NR variable Post Regression test

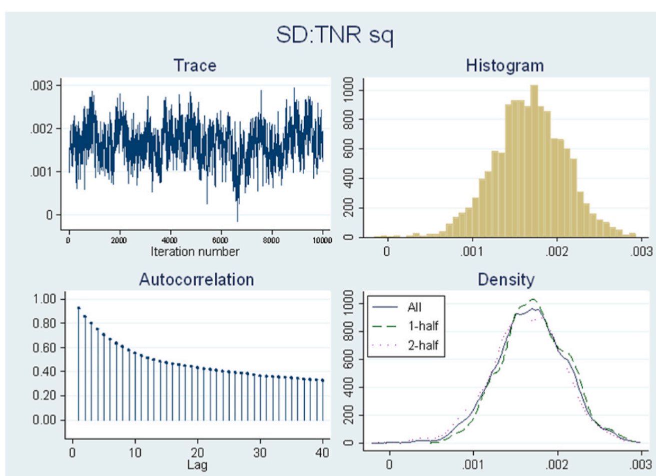

Fig. 7. NR sq variable Post Regression test

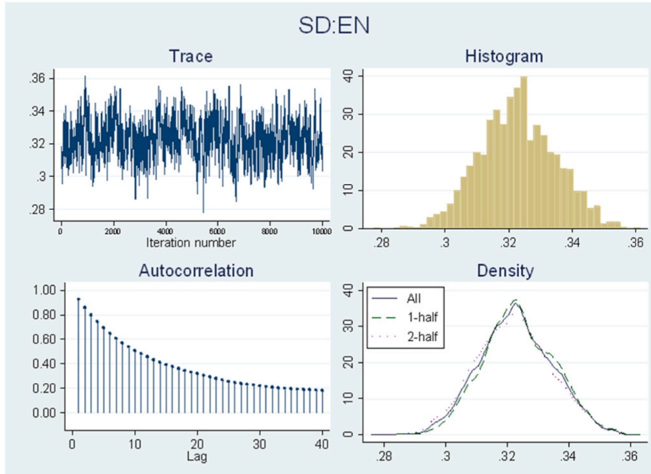

Fig. 8. EN variable Post Regression test

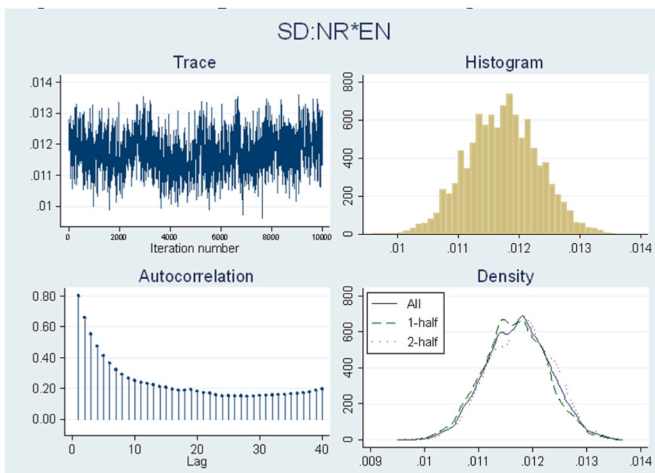

Fig. 9. NR*EN variable Post Regression test

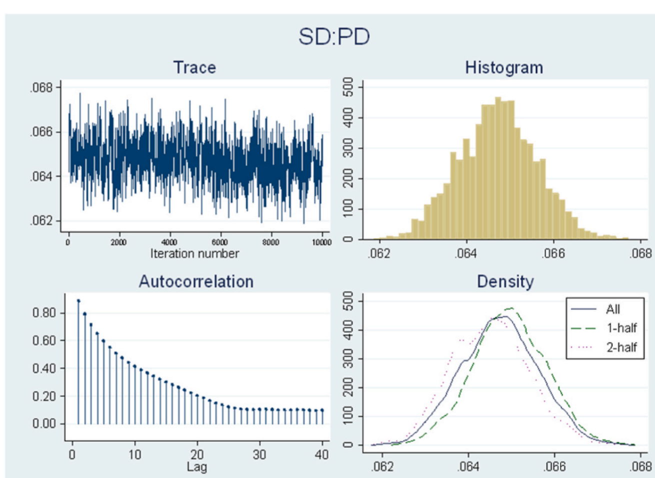

Fig. 10. PD variable Post Regression test

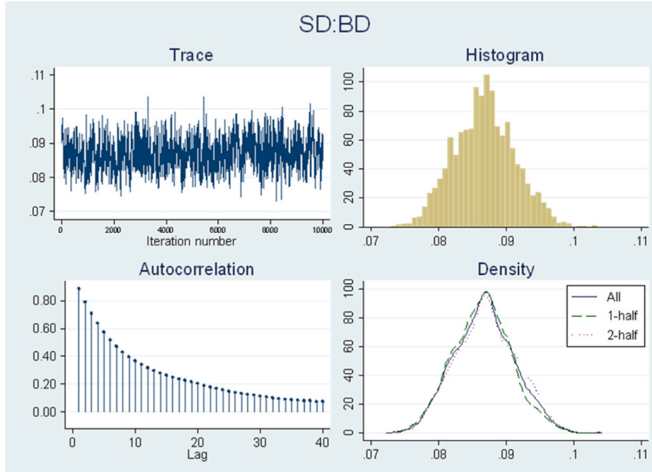

Fig. 11. BD variable Post Regression test

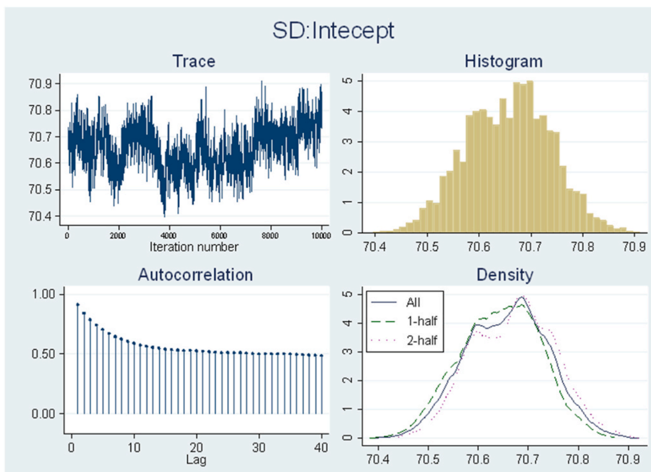

Fig. 12. Intercept Post Regression test

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