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Environmental Impact Assessment Based on STIRCEFUPAIT Modelling Framework – Need for Transition towards Green Energy

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Abstract

The study analyses environmental emissions based on the STIRCEFUPAIT modelling framework applying energy consumption, production efficiency, non-renewable energy mix, urbanization, population, affluence and innovation-technology as the studied variables. The impact and contribution of the variables to the change in Environmental impact has been analysed using ridge regression analysis. The findings suggest that environmental impact can be tackled by switching to environmental innovation practices and green energy usage.

Keywords: *Energy Consumption, Sustainable Production, Sustainable Consumption, Ridge Regression, Green Energy*

INTRODUCTION

The past two decades have been a witness to remarkable economic development in the emerging economies but at the cost of fossil fuel emissions and deteriorating environmental conditions. Numerous studies have cited the hefty impact of household carbon dioxide emissions (HCEs) apart from industrial emissions on account of their detrimental impact on the environment (Yu et al., 2023). Growth in population, urbanization, GDP and energy consumption postulates incremental pressure on environment pertaining to rise in demand for energy and natural resources especially in the context of highly populated fossil fuel driven growth oriented emerging economies (Yu et al., 2023). For an emerging economy high per capita GDP

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is desirable for the economic prosperity of the nation but Environmental impact management should be undertaken through rigorous sustainable consumption and Environmental stewardship practices (Biswas & Roy, 2015; Biswas, 2017). Studies have depicted that population, affluence, urbanization rate, industrialization level had significant impact in raising environmental emissions (Wang et al., 2013; Kilbourne & Thyroff, 2020; Xue et al., 2022). It has been estimated that if environmental emissions are not controlled soon then ambient concentrations of particulate air pollution will cause health hazards to million lives in developing countries which necessitates the study of Environmental impact assessment in the developing nations experiencing fossil-fuel based market-driven growth such as India. Applying statistical data between 2000 and 2020 in the context of India this study tries to develop an extended stochastic impact by regression on population, affluence and technology (STIRPAT) model to prognosticate sway of the major impacting variables on the environment and how adoption of sustainable practices would lead towards a transition in this emerging economy.

REVIEW OF LITERATURE

A research program generated the STIRPAT model, a statistical model generated for assessing the Environmental impacts which was developed in the US in the mid-1990s. The model has constantly been refined and applied for empirical analysis and policy recommendations based on several parameters (Kilbourne & Thyroff, 2020; Xue et al., 2022). The predecessor of the STIRPAT model is the IPAT which allows estimation of the proportionate impact on environment by changing one factor while simultaneously holding the others constant. IPAT model was an accounting equation balancing of which was mandatory, to remove this limitation, it was reformed into the probabilistic STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model. The total Environmental impact has been assessed as a multiplicative function of size of population (P), affluence (A) described as per capita consumption or production and (T) signifying the level of Environmental damage caused by technology per unit of production or consumption (Ehrlich & Holdren, 1971).

RESEARCH METHODOLOGY

The extended STIRPAT model was formulated with incorporation of some macroeconomic variables based on the purpose of the study. The Environmental impact assessment has been undertaken with the help of regression analysis and ridge regression has been applied to minimise the impact of multi-collinearity among the studied variables.

Modelling Framework

The standard STIRPAT model was formulated as follows:

$$I_i = a\, P^b_i A^c_i T^d_i e_i \qquad [1]$$

It retains the multiplicative logic of I=PAT equation.

After taking the logarithms, the model becomes:

$$\ln I = a_0 + a_1 \ln P + a_2 \ln A + a_3 \ln T + \ln e \qquad [2]$$

Here the a_1, a_2 and a_3 denotes the coefficients of P, A and T respectively and a_0, the constant and e- the error.

Alteration of variables is permitted in the STIRPAT model till the multiplicative model specification is not hindered (York et al., 2003). Hence this paper revises Eq. [2] by adding Energy consumption (C), Production Efficiency (E), Non Renewable Energy mix (F), Urbanization Rate (U) and Innovation-Technology (IT) to Population (P) and Affluence (A) resulting in Eq. [3].

$$\ln I = a_0 + a_1 \ln C + a_2 \ln E + a_3 \ln F + a_4 \ln U + a_5 \ln P + a_6 \ln A + a_7 \ln IT + \ln e \qquad [3]$$

Description of the variables used in the analysis of the underlined model has been provided in Table 1.

Data Source

The data provided in this study has been derived from the World Bank data source, Ministry of Finance and Ministry of Electronics and Information Technology, GOI (2000-2020).

Table 1: Variable Settings and Statistical Description of STIRCEFUPAIT

Variables	Description	Symbol
Environmental emissions	CO_2 emission from fossil fuel combustion	I
Energy Consumption	Total energy consumption divided by total population	C
Production Efficiency	Total GDP divided by Fossil fuel consumption	E
Non Renewable Energy mix	Fossil fuel consumption divided by total energy consumption	F
Urbanization	Urban population divided by total year end population	U
Population	Total Population	P
Affluence	Gross Domestic Product divided by Total Population	A
Innovation-Technology	Government IT Expenditure divided by GDP	IT

Studied Variables

Urbanisation (U) and Population (P)

The consideration of this factor in the STIRCEFUPAIT model has been necessitated for the country is experiencing a significant rise in its urbanization level in the past few decades.

Energy Consumption (C), Production Efficiency (E) and Non Renewable Energy Mix (F)

For any emerging economy the importance of production efficiency is remarkable as the optimisation of fossil fuel usage per unit of effective production through adoption of effective energy conservation measures or adoption of green energy would make more energy available for economic activity and minimise Environmental impact simultaneously. Rapid economic growth and unprecedented rise in energy consumption for both household and industrial purpose have provoked the policy makers in emerging economies to substitute fossil fuel by cleaner energy sources. There has been an unprecedented escalation in the number, quality and availability of energy consumption expenditures consequent to emerging economies with research endeavouring upon the inclination of rise in

Environmental emissions with rise in income and household consumption expenditure. The high ratio of fossil fuel production/usage to total energy production/usage needs is a matter of serious concern.

Affluence (A)

Augmentation in GDP per capita will encounter changes in economic structure, increase in purchasing power, changes in consumption pattern and transition from rural to industrialized activities which would eventually cause Environmental degradation (Wang et al., 2014). Rise in affluence will cause a transition from an organic lifestyle to a more mechanistic lifestyle causing enhanced energy and resource consumption. Rise in unsustainable household energy consumption based on non-renewable sources is a major genesis of Environmental deterioration (Yu et al., 2023).

Innovation and Technology (IT)

Technology level measured in terms of Government IT Expenditure per unit of GDP has been rigorously applied in a wide array of studies for assessment of Environmental impact. Technology and innovation are inextricably intertwined. Improved innovation and disruptive technology will enhance GDP so the components of technology and innovation have been merged together. Investments may propagate emergence in the level of technology with clean technology/green energy transcending environmentally harmful technologies, which have been highly appraised in the developed nations while there is slack in the emerging counterparts.

RESULTS AND ANALYSIS

The Indian economy has witnessed a rapid average annual growth in Environmental emissions caused by the cumulative rise in GDP, population, urbanization, affluence, innovation-technology and energy consumption (Table 2). The rise is urbanisation and population is succeeded by increase in total energy consumption. Energy consumption coupled with GDP has increased four-fold in comparison to urbanisation and population annually which highlights the rising energy demand by the households and industries and an immediate need to switch to renewable sources of energy such as wind, solar, biogas and hydel power. Growth in GDP and IT will foster more investment and reinvestment avenues and in course will enhance energy consumption.

Table 2: Growth Rates of the Variables

Variables	Total Growth Rate (%)	Average Annual Growth Rate (%)
I	223.15	10.63
C	279.80	13.32
E	14.67	0.70
F	41.60	1.99
U	74.85	3.56
P	43.78	2.08
A	282.20	13.44
IT	148.70	7.08

Ridge Regression Estimate

An OLS Regression was conducted and to reduce multicollinearity Ridge Regression was conducted. The multicollinearity problem can be subdued with the help of Ridge Regression analysis without omission of any variables (Lin et al., 2009). This method requires a conservative selection of Ridge Regression coefficient K. As it is a biased estimation, a small value for K should be chosen as far as possible with steady going regression coefficients. In this case K was calculated with a step length of 0.05 changing within (0, 1). When K was equal to 0.10, the variables' coefficients were steady with small VIFs. This is the value used for estimation of the STIRCEFUPAIT model in Table 3 (Lin et al., 2009; Wang et al., 2013).

R square of 0.98 signifies good overall fit. The value of F-statistic is significant at 0.01 level. Therefore, the fitted ridge regression equation based on Eq. (3) is

$$\ln I = 2.48 + 0.68\ln C + 6.78\ln E + 2.64\ln F + 1.38\ln U + 0.76\ln P + 0.87\ln A + 0.09\ln IT \quad [4]$$

Table 3: Ridge Regression Results (K=0.10)

Variables	B	S.E	T
Constant	2.56	0.06	9.88
C	0.68	0.05	8.95
E	6.78	0.72	3.58
F	2.64	0.14	11.31
U	1.38	0.11	10.09

Variables	B	S.E	T
P	0.76	0.06	9.05
A	0.87	0.25	8.99
IT	0.09	0.03	2.03
Error term 0.02 R^2 0.98 Adjust R^2 0.97			

According to the signs of the coefficients in Eq. (4), it is evident all the variables have positive impact on environmental emissions or on environment impact assessment. The importance of the Environmental impact factors can be expressed by the absolute values of the elastic coefficients in descending order as E>F>U>A>P>C>IT.

Table 4: Contribution of the Variables to the Change in Environmental Impact

Variables	Average Annual Growth Rate	Regression Coefficient	Compounded Effect on Environmental Impact	Contribution Degree to the Change of Environmental Impact
I	10.63			
C	13.32	0.68	9.06	0.85
E	0.70	6.78	4.75	0.45
F	1.99	2.64	5.25	0.49
U	3.56	1.38	4.91	0.46
P	2.08	0.76	1.58	0.15
A	13.44	0.87	11.69	1.10
IT	7.08	0.09	0.64	0.06

Compounded Effect on Environmental impact = Average annual growth rate X Regression coefficient.

Contribution degree to change of Environmental impact = Compounded Effect on Environmental impact ÷ Average annual growth rate of Environmental emissions.

CONCLUSION AND DISCUSSION

Table 2 and Table 3 suggests that there has been a significant rise in the average annual growth rate of environmental emissions which

is corroborated by the significant growth in affluence and energy consumption. An emerging economy like India is witnessing significant fossil fuel driven growth in its GDP with high rate of industrialisation. There has been a rise in fossil fuel consumption to cater to industrial, household energy needs and growth in intensive technology usage owing to unprecedented rise in urbanisation and population. (Table 3) Impact of Production efficiency is highest on environmental emissions. GDP is increasing at the behest of fossil fuel consumption. Contribution of non-renewable energy mix is significantly high on environmental emissions. Fossil fuel stills accounts for a major portion of total energy production/consumption which needs urgent crack down and switch to alternative green energy sources. IT has the least impact on environmental emissions as higher Governmental investments to promote Innovative and Information Technology will also attract investments from venture capitalists and qualified institutional investors in similar area. Many Indian large and midcap Companies are resorting to voluntary annual business responsibility and sustainability reporting practices with focus on environmental consideration indicators, environment policy, environmental management system and disclosure of qualitative and quantitative data about environmental care. But still the disclosure is limited. Higher per capita investment in IT will minimise the detrimental impact on environment through development of improved energy efficient operations and products. This shall also lead to Intellectual Property development and foster innovations in green energy and green technology. Acceleration of industrial structure through active propagation of high-tech and tertiary high value added but low energy intensive industry can be proposed.

In order to mitigate the Contribution degree to the change of Environmental impact (Table 4), of fossil fuel consumption, affluence, production efficiency and urbanisation environmental stewardship and sustainable production practices in the form of product and process stewardship, re-cycling, effective waste management, embracing clean technology and green energy sources in the form of hydro power, solar power, wind power, biogas, natural gas.

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