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UNEARTHING SUSTAINABLE FOOTPRINTS IN THE G21 COUNTRIES - AN EMPIRICAL EVIDENCE

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Abstract *Energy serves as one of the most important strategic commodities that either advances or impedes economic development and can affect the environment positively or negatively. Amidst the ongoing planetary crisis, the research problem of the current study is to focus on exploring the relationship between various macroeconomic factors and sustainability with special attention to renewable and Non-Renewable Sources of Energy (NREC) in the context of G21 countries during 2002–2022. The underlined variables i.e., GHG emissions, NREC, REC, urbanisation, stock prices, trade openness, Foreign Direct Investment (FDI), and economic growth were selected to identify the nexus between the dependent and independent variables used in different models of the study. The research data and variables adhere to a panel dataset; therefore, Generalised Linear Models (GLM) and Generalised Method of Moments (GMM) techniques were used to analyse the data. Based on the findings, it is recommended that the government should impart knowledge, organise awareness and training programmes in these countries to give social recognition and acceptance to renewable and alternative sources of energy.*

Keywords: *Renewable Energy, Non-Renewable Energy, GHG Emissions, Energy, Sustainable*

JEL Code: *Q01, Q2, Q56*

INTRODUCTION

Since the dawn of the Industrial Revolution in the late 18th century, industrial economies have been aiming to increase the production of goods to improve the quality of life for millions of people around the globe. However, these developments have one of the most antagonistic effects in terms of environmental degradation. The modernised world is moving towards an "ecological credit crunch" where humans have been excessively consuming Earth's natural resources to support their economy and society. The current economic model is running out of road as it creates excessive pressure on finite non-renewable resources which eventually diminish over time.

The present study investigates the nexus between renewable and non-renewable energy in relation to sustainability in the context of G21 countries. The G21, or Group of 21 members, is a forum for international economic cooperation and coordination. It is composed of major economies encompassing both developed and developing nations, representing "85% of the world's GDP, 80% of international trade and approximately 60% of the global population" (Appiah-Otoo et al., 2023). It is evident from the statistics that over the period from 2000 to 2021, fossil fuel consumption surged from 71,886 TWh to 103851 TWh, reflecting a substantial increase of 45 per cent and posing environmental risks along with vulnerabilities related to shortages of fuel supply and energy security (Appiah-Otoo et al., 2023).

The present study considers the influence of non-renewable and renewable sources of energy on the environment in the context of G21 nations from 2002–2022. Further, the study classifies the G21 member countries into clean and dirty countries. The categorisation is determined based on the Ecological Footprint (EF) scores.

The findings of the study reveal that non-renewable energy positively impacts GHG emissions in the case of the dirty countries panel. Non-Renewable Energy (NRE) positively impacts GHG emissions even in the case of the clean countries panel. The findings of Model 3 revealed that as the consumption of renewable energy increases in the case of the dirty countries panel, the GHG emission also increases. The findings of Model 4 recognised that renewable energy has a negative relation with GHG emissions in the case of the clean

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countries panel. As the clean countries panel which majorly comprises developed and richer nations, incorporates green sources of energy in their energy grid, it effectively reduces emissions fostering environmental quality.

Further, the study theoretically examines if there are any appreciable differences between the macro-economic variables and renewable and non-renewable energy sources. In addition, government authorities are advised to impart knowledge, organise awareness and conduct training programmes for the countries with the objective to give social recognition and acceptance to renewable and alternative sources of energy. The countries must formulate stringent policies to curb carbon leakage and production-based emissions within their domestic territories. Both the clean and dirty countries panel should build efficient infrastructure and shift its focus on renewable energy in a phased manner. There should be awareness among investors about corporate sustainability and the triple-bottom line to attract and retain the investors and other stakeholders. Dirty countries should gain an understanding of the importance of balancing economic growth and its undesirable by-product, such as emissions. The research paper is further classified into a review of the literature, research methodology, analysis and interpretation, summary and conclusion, policy implications, and limitations along with scope for future research.

REVIEW OF LITERATURE

The empirical studies in this field are divided into two main strands of literature. The first strand concentrates on assessing the influence of NREC on various macroeconomic variables, while the second strand seeks to identify and analyse the impact of REC on macroeconomic variables.

Impact of Non-Renewable Energy Consumption on Different Macroeconomic Variables

Ang (2007) investigated the dynamic causal connections among pollutant emissions, energy consumption, and output in France from 1960–2000. The findings revealed the presence of a long-term relationship between these underlying variables. Chang (2010) revealed that energy consumption is positively correlated with GDP growth, while coal consumption and CO_2 emissions exhibit bi-directional causality with a feedback effect. Bloch (2012) investigated the relationship between coal consumption and GDP in China from 1977 to 2008 and 1965 to 2008 employing both a supply-side and a demand-side analysis, respectively. The empirical findings revealed a one-way causality, with coal consumption influencing GDP positively in both the short and long term under the supply-side analysis in China. Li and Lueng (2012) assessed the nexus between coal consumption and real GDP in China using panel data for 23 years. Results indicated that coal consumption and GDP were both integrated of order one and were cointegrated across all regional groupings. Contrary to the expectations of the EKC hypothesis, the relationship between GDP and pollution remains positive in both the short and long run based on the results obtained, as found by Al-Mulali et al. (2015).

Impact of Renewable Energy Consumption on Different Macroeconomic Variables

Chien and Hu (2008) employed Structural Equation Modelling (SEM) to investigate the impact of renewable energy on the GDP of 116 economies in 2003. The study affirmed a positive relationship between renewable energy and GDP. This has been ratified by Chien and Hu (2007); Tiwari (2011). On the other hand, Silva et al. (2012) found a negative relationship between renewable energy and carbon emissions. Soukiazis et al. (2017) suggested that Internet usage and economic growth contributed to long-term increases in electricity consumption, primarily from non-renewable sources in developed countries, highlighting the need for sustainable energy practices. Khobai (2018) indicated a causal relationship running from REC, CO_2 emissions, capital, and employment to economic growth in the long run, suggesting that REC contributes positively to Indonesia's economic prosperity.

Research Gap

The present study is distinctive and adds value to the existing literature on three parameters. First, this is one of a kind of its study considering G21 nations. Many studies in the past have examined various regional blocs, however, the G20 was transformed into G21 in September 2023. Thus, because of this recent modification, the sample chosen for our study is unique. The G20 is also considered a sustainable group that promotes energy transitions and sustainable growth (Swain et al., 2024). Second, past researchers have segregated the selected countries on the basis of different parameters. For instance, developed, developing, and industrialised. However, the present study deals with the classification of these countries based on their clean and dirty status using ecological footprint scores calculated by the Global Footprint Network. Third, the strength of any economy can be determined by its financial system. The banking system is more prevalent at low-levels of economic development while stock markets dominate at high-levels of economic development. Past studies have focused upon benchmark indices to represent stock movements in a country which might be erroneous to compare international markets. In contrast, the current work considers stock traded as a proxy, which includes measures of size and liquidity as a percentage of GDP.

OBJECTIVES OF THE STUDY

- H_{01}: To empirically identify the relationship between carbon emissions and non-renewable sources of energy.
- H_{02}: To empirically identify the relationship between carbon emissions and renewable sources of energy.
- H_{03}: To theoretically examine whether there are any appreciable differences between the effects of economic factors when considering renewable and non-renewable energy sources.
- H_{04}: To make policy recommendations that different stakeholders can take into account.

RESEARCH METHODOLOGY

For the purpose of attaining the aforesaid objectives, the analysis is carried out on the data collected for the G21 or the Group of 21 members. The G21 is made up of the world's biggest developing and developed economies, including Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey (Türkiye), United Kingdom and the United States of America, the regional bloc of the European Union, and the recently included permanent member African Union.

Further, the G21 members were then classified as clean and dirty countries. The categorisation into clean and dirty countries was determined based on the Ecological Footprint (EF). The Ecological Footprint is a score calculated by the Global Footprint Network, an international non-profit organisation, annually on the basis of data relating to built-up land, carbon, crop land, fishing grounds, forest products, and grazing land. Based on the scores collected, the EF further segregates a nation as ecologically deficient or ecologically surplus.

Interestingly, the Environmental Performance Index (EPI) also provides a scale for categorisation. However, deeper inquiry into the EPI methodology led us to believe that the organisation uses different metrics to measure the environmental performance each year. This makes index values non-comparable for trend analysis and hence, EF, and not EPI, was considered for the bifurcation. Table 1 below depicts the classification of the countries into clean and dirty countries panels.

Table 1: Classification of Countries into Clean and Dirty Countries

Clean Countries	Dirty Countries
Argentina	China
Australia	France
Brazil	Germany
Canada	India
Russian Federation	Indonesia
Sub-Saharan Africa	Italy
	Japan
	Korea, Rep.
	Mexico
	Saudi Arabia
	South Africa
	Türkiye
	United Kingdom
	United States
	European Union

Source: Authors' computation.

It is pertinent to note that we have considered Sub-Saharan Africa as a proxy for the latest permanent member of the G20 nations, i.e., the African Union. The classification is based upon the consolidated ecological reserves and deficits since 1961 calculated by the Global Footprint Network. We have run four models, two each for dirty and clean country panels where the independent variables vary according to the first and second objectives.

Data Collection and Sources

The data analysis was conducted using EViews. The study covers annual data ranging from 2002–2022 for the current project. The choice of the initial year was made keeping into consideration the availability of Ecological footprint data on its official website since 2002 onwards and the cut-off data has been decided based on the data availability factor. The data was extracted from secondary sources such as open databases maintained by the World Bank and the Statistical Review of World Energy and is tabulated in Table 2.

Table 2: Data Collection

Explanatory Variable	Symbol	Data Collection Source
Renewable Source Consumption	LN_RE	Statistical Review of World Energy
Non-Renewable Source Consumption	LN_NRE	Statistical Review of World Energy
Foreign Direct Investment	LN_FDI	World Development Indicators, World Bank
Gross Domestic Product per Capita	LN_GDP	World Development Indicators, World Bank
Urbanisation	LN_POP	World Development Indicators, World Bank
Stock Movements	LN_SHARE	World Development Indicators, World Bank
Trade Openness	LN_TRADE	World Development Indicators, World Bank

Source: Authors' computation.

The research data and variables adhere to panel datasets; therefore, Generalised Linear Models (GLM) and Generalised Method of Moments (GMM) techniques were used to analyse the data collected after checking for cross-sectional dependence and stationarity of variables. The underlined variables i.e., Greenhouse Gas (GHG) emissions, Non-Renewable Sources of Energy (NREC), Renewable Sources of Energy (REC), urbanisation (POP), stock prices, trade openness, Foreign Direct Investment (FDI), and economic growth (GDP) were selected to identify the nexus between the dependent and independent variables used in different models of the study for the time-period 2002–2022.

ANALYSIS AND INTERPRETATION

The current research aims to analyse the impact of various significant macroeconomic factors on the renewable and non-renewable energy in the G21 countries. The countries that highlight the differences significantly while conducting a comparative analysis are selected based on the clean and dirty countries.

Countries are classified as dirty or clean with respect to emissions. According to ecological footprint scores, developed nations like Germany, Japan, the United Kingdom, and the United States of America are on the negative side of using more nature resources than can be replenished naturally. Thus, we can conclude that these countries work more like developing nations having high ecological footprint scores. In a nutshell, we can say that the countries which are high on consuming more natural resources than their capacity are included in the dirty countries panel and vice-versa for clean countries.

Model 1 - Dirty Country Panel – Treating Non-Renewable Energy as the Independent Variable

Focusing on identifying the relationship between macroeconomic factors responsible for environment degradation in the dirty country panel, we examined the existence of a panel unit root, autocorrelation, and cross-sectional dependence.

To determine the existence of a panel unit root for the selected variables using Levin, Lin and Chu and Im, Pesaran, and Shin W-stat tests and found that all the variables were stationary at either the level or first difference. Further, to check for cross-sectional dependence, we conducted a residual cross-section dependence test, the null hypothesis which states that no cross-section dependence in residuals. However, because the p-value is significant we reject the null hypothesis. Therefore, in order to correct it, we applied a cross-section SUR (GLS) test in response to the rejection of the null hypothesis. After checking the preliminary tests, we used the GMM to recognise the macroeconomic factors behind the environmental degradation in the panel of dirty countries.

Table 3: Results of the Dirty Country Panel-NRE as Independent Variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_GHG (-1)	0.33601	0.08306	4.045437	0.0001
LN_NRE	0.646672	0.10336	6.256376	0.0000
LN_FDI	0.000311	0.00357	0.087226	0.9306
LN_GDP	-0.04728	0.02054	-2.30213	0.0221
LN_POP	-0.00456	0.14976	-0.03042	0.9758
LN_SHARE	0.016198	0.01156	1.401694	0.1622

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_TRADE	-0.07242	0.0226	-3.20401	0.0015
Mean dependent var	0.004005	S.D. dependent var		0.04555
S.E. of regression	0.039626	Sum squared resid		0.40669
J-statistic	11.75433	Instrument rank		16
Prob(J-statistic)	0.227516			

Source: Authors' computation.

Table 3 suggests that non-renewable energy positively impacts GHG emissions. This means that as a country utilises a non-renewable form of energy for any purpose then the environment degrades at a lesser rate. In the current scenario, the majority of the countries are reliant on non-renewable energy for the efficient utilisation of resources and the expansion of output leading to industrialisation. Majorly, emerging and developing countries include NRE as a major component in their energy mix. Further, GDP representing economic growth and trade openness proxied by trade significantly affect the emissions negatively. To elaborate, this means that as the economic output expands, the emissions reduce with a negligible amount significantly.

We found that non-renewable energy holds a significant portion of the energy grid of developing countries, on the other hand, increasing GDP lowers emissions. This leads to the conclusion that developing nations attempt to adopt energy efficiency in the backdrop of excessive emphasis on producing sustainably. Also, it corroborates with the second phase of the Environmental Kuznets Curve (EKC) curve which means as the economic output expands, emissions reduce. The possible justification could be that these countries have built strong and efficient infrastructure and there is a dominance of technological effect.

Lastly, trade openness also exhibits a negative relation with GHG emission. An increase in trade openness could be translated into increasing the export and import basket of countries. Particularly, most developing nations are export-led economies and their export concentration has risen over years. The urge of the developing nations to follow the increasing trajectory of economic growth allows FDI to enter their territories. This leads to a technology effect as foreign countries bring in with them advanced technologies leading to effective production. Thus, we can safely assume that trade openness decreases the level of emission on the pretext of technological effects (Karedla et al., 2021). Moreover, exporting countries usually produce in conformity with the rules, regulations, and standards set by importing countries. Thus, exporting countries are forced to produce sustainably. Bhatia and Tiwatne (2018) point out the probable opportunities and challenges of FDIs with respect to India. However, FDI, urbanisation and share prices do not affect emissions.

Model 2 - Clean Country Panel – Treating Non-Renewable Energy as the Independent Variable

We checked for the presence of cross-section dependence using the Breusch-Pagan LM test and the Pesaran CD test. We found that the p-value was more than the 5% level of significance indicating no cross-sectional dependence among the variables in the model. Further, we also checked for heteroskedasticity using the Panel Period Heteroskedasticity LR Test, for which the null hypothesis states that residuals are homoscedastic.

Table 4: Results of the Clean Country Panel - NRE as Independent Variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_NRE	0.742535	0.018966	39.15026	0.0000
LN_FDI	0.037472	0.020752	1.805704	0.0710
LN_GDP	-0.091246	0.022036	-4.140851	0.0000
LN_POP	0.136922	0.026957	5.079373	0.0000
LN_SHARE	0.117423	0.016253	7.224546	0.0000
LN_TRADE	0.006087	0.142053	0.042848	0.9658
C	12.26630	0.274080	44.75450	0.0000
Mean dependent var	13.75342	S.D. dependent var		0.663968
Sum squared resid	1.396383	Log likelihood		94.22829

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Akaike info criterion	-1.478446	Schwarz criterion		-1.314083
Hannan-Quinn criter.	-1.411709	Deviance		1.396383
Deviance statistic	0.012580	Restr. Deviance		51.57980
LR statistic	3989.133	Prob (LR statistic)		0.000000
Pearson SSR	1.396383	Pearson statistic		0.012580
Dispersion	0.012580			

Source: Authors' computation.

Table 4 suggests that there exists a positive relation of NRE, FDI, urbanisation, and share prices with GHG emissions. To elaborate, as the consumption of non-renewable energy increases, the environmental quality reduces as the hazardous emissions rise. Though we are studying and analysing the clean country panel, it does not mean that the countries included in the panel have completely transitioned to clean sources of energy. The energy matrix is a combination of renewable and non-renewable forms of energy and thus, if we consume NRE, then the environment degrades.

Further, as FDI increases, the emissions also increase at a 10% level of significance. Huang (2022) found that FDI positively impacts the carbon emission but when the economic development is accompanied with high FDI flows, it mitigates the carbon emission. Shahbaz (2019) points out that the USA which has imposed stringent environment rules and among the top rank-holder in EPI has still not capitalised on the opportunity of FDI bringing in cleaner technologies. The same has been supported by Lau et al. (2014). Thus, we can safely assume that clean countries have also not capitalised fully on the benefits of greener technologies via FDI. However, it is pertinent to note that the coefficient is negligible and chances of incurring Type 1 error are high at the 10% level of significance.

Also, we have noticed a positive relation between urbanisation and emissions which indicates that urban activities lead to more emissions. Lastly, share prices also increase emissions because of higher investment and productivity leading to higher energy use. We noted that trade openness does not have a significant relation with GHG emissions.

Model 3 - Dirty Country Panel – Treating Renewable Energy as the Independent Variable

The panel is tested to explore the relationship between REC and carbon emissions. Firstly, we have checked the existence of unit root using Levin-Lin Chu and lm Pesaran and Shin W-stat. We found that all the variables are stationary either at the level or at the first difference. The model has also been tested for CSD and autocorrelation. The results suggest that all the preliminary tests are satisfactory and thus, we applied the GMM.

Table 5: Results of the Dirty Country Panel - RE as Independent Variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_GHG(-1)	0.45601	0.08141	4.0141	0.001
LN_RE	0.004758	0.022848	0.208230	0.0352
LN_FDI	0.093201	0.086637	1.075773	0.2830
LN_GDP	0.194488	0.048705	3.993183	0.0001
LN_POP	0.783123	0.265804	2.946236	0.0035
LN_SHARE	0.082909	0.037042	2.238268	0.0261
LN_TRADE	-0.338320	0.120443	-2.808959	0.0054
Mean dependent var	0.004005	S.D. dependent var		0.137335
S.E. of regression	-0.009440	Sum squared resid		3.457918
J-statistic	0.115995	Instrument rank		6
Prob(J-statistic)	0.2429			

Source: Authors' computation.

Table 5 suggests that as renewable energy increases, GHG emissions also increases significantly at the 5% level of significance. This points out the fact that as dirty countries look for cleaner alternative sources of energy, there is a positive impact on the environment as the degrading impact has been lowered when compared to Model 1. Climate change summits and various protocols in accordance with environmental sustainability involve the participation of developing nations, which make them to include greener sources of energy in their energy grid. However, developing nations take time to transition from an NRE consumption economy to an RE consumption economy. The coefficient (0.004578) is negligible which indicates that adoption of renewable energy along with fossil fuels increases the emission at a slower rate. Also, Saidi and Omri (2020) found that there exists a positive relation between renewable energy and carbon emission as there is lack of awareness among the residents of the dirty nations regarding the importance of renewable energy consumption.

The same can be ratified by the relationship between GDP and GHG emissions. As economic output expands, so do GHG emissions. Production levels in developing economies are still reliant on the use of fossil fuels because of their affordability. Renewable energy on the other hand is expensive and thus, refrain the emerging nations from adopting it and rely on it fully. Further, urbanisation directly impacts the GHG emissions at the 5% level of significance (Sadorsky, 2014; Luqman et al., 2023). A report by UN Environment Programme claims that urban activities are the main source of carbon emissions with transport and buildings being the biggest culprits.

We also observe that share prices have a positive impact on GHG emissions at a 5% level of significance. Moving in reverse order, an increase in share prices means higher investment leading to higher productivity and energy use. Thus, higher energy use in the dirty economies increases the carbon emissions (Alessi et al., 2021; Shobande et al., 2021). Lastly, trade openness affects GHG emissions negatively. A larger export and import basket, with an emphasis on export-led economies brings in the role of NREC leading to environmental deterioration. FDI however, does not impact greenhouse emissions significantly.

Model 4 - Clean Country Panel – Treating Renewable Energy as the Independent Variable

The unit root test indicates that all the variables used in the model are stationary at either the level or at the first difference. For this, we have used the Levin, Lin and Chut, and Im, Pesaran and Shin W-stat tests. Also, we have tested cross-section dependence using the Breusch-Pagan LM test and the Pesaran CD. Both tests indicate that no cross-section dependence exists in the model.

Table 6: Results of the Clean Country Panel - REN as Independent Variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LN_REN	-0.218102	0.028026	-7.782102	0.0000
LN_FDI	-0.147299	0.059741	-2.465629	0.0137
LN_GDP	0.192107	0.081517	2.356647	0.0184
LN_POP	0.852417	0.117734	7.240203	0.0000
LN_SHARE	0.631676	0.047285	13.35878	0.0000
LN_TRADE	-0.677467	0.124676	-5.433820	0.0000
C	6.300500	1.267890	4.969280	0.0000
Mean dependent var	13.74768	S.D. dependent var		0.664283
Sum squared resid	13.08524	Log likelihood		-36.62565
Akaike info criterion	0.703639	Schwarz criterion		0.862849
Hannan-Quinn criter.	0.768314	Deviance		13.08524
Deviance statistic	0.111840	Restr. Deviance		54.27639
LR statistic	368.3054	Prob (LR statistic)		0.000000
Pearson SSR	13.08524	Pearson statistic		0.111840
Dispersion	0.111840			

Source: Authors' computation.

Table 6 suggests that renewable energy has a negative relation with GHG emissions. It indicates that as a clean country panel, which majorly comprises developed and richer nations, incorporates green sources of energy in its energy grid, it effectively reduces emissions, fostering environmental quality. Further, FDI also indicates that it impacts emissions negatively. This points to the pollution halo hypothesis as clean countries focus on taking advantage of advanced technology from the FDI inflows. It is pertinent to note that the coefficient is moderately high and significant at the 5% level of significance when compared to Model 2.

Further, economic growth, urbanisation, and share prices positively and significantly impact GHG emissions. The probable reasons for the obtained relationship could be that industrialisation increases in response to rising GDP which ultimately deteriorates the environment. The factors of production namely, capital, labour, and energy results in desirable and undesirable outputs. The desirable being the GDP whereas undesirable output which is also known as the by-product of GDP is emissions. Thus, even though the clean countries focus largely upon greener technologies and sources of energy, still the use of NREC has not been completely eliminated. Further, as the urban activities rise, so do the transportation and buildings lead to poor environment quality. Next, share prices also signifies positive relation with respect to GHG emissions. Lastly, trade openness exhibits negative relation which indicate that the clean country panel is cautious in entering into trade agreements with the rest of the world and attempts to minimise carbon emission through either production or consumption. This largely means that the lifestyle of the residents is superior since they demand green products leading to lower consumption-based emissions.

Table 7: Comparative Analysis

Variable	Dirty Countries		Clean Countries	
	Model 1	Model 3	Model 2	Model 4
Energy Source	0.646672*	0.004758*	0.742535*	-0.218102*
FDI	0.000311	0.093201	0.037472**	-0.147299*
Economic Growth	-0.04728*	0.194488*	-0.091246*	0.192107*
Urbanisation	-0.00456	0.783123*	0.136922*	0.852417*
Share Movement	0.016198	0.082909*	0.117423*	0.631676*
Trade Openness	-0.07242*	-0.338320*	0.006087	-0.677467*

*significance at 0.05 level; ** significant at 0.10 level.

Comparative Analysis of Objective 1 and Objective 2

- *Energy Source:* As per the literature, inclusion of RE should have a negative impact on GHG. But since the countries are in the dirty panel, it will take them a substantial amount of time to transition from the consumption of non-renewable energy sources to renewable energy sources. Thus, the impact is observed as positive (0.0047) but negligible. Therefore, we can say dirty countries are on the right path towards sustainability. Further, the results obtained in Model 1 validate that dirty countries rely heavily on NRE, ratified by the positive and significant coefficient (Table 7). On the other hand, for clean countries the impact of NRE and RE on GHG Emissions is estimated to be significant with positive and negative coefficients respectively. The results obtained are in line with those obtained by Saidi and Omri (2020).
- *Foreign Direct Investment:* For dirty countries, they rely more on NRE, the results are positive and insignificant. But for clean countries, given the consumption of RE, the impact of FDI on emissions is negative and significant, implying that global investors and conglomerates are interested in investing in local companies which rely more on renewable sources of energy. Availability of resources and funds in the form of FDI helps companies better utilise them and reduce emissions in the environment.
- *Economic Growth:* Dirty countries have a past record of relying on NRE. Thus, given the consumption of NRE, the dirty countries have efficient technology (for instance clean coal-fired plants) to utilise the NRE sources in such a manner that an increase in GDP per capita contributes negatively towards the GHG emissions. On the other hand, massive initial infrastructure requirements for the consumption of RE, makes it difficult for the dirty countries to take the full advantage of RE, despite an increase in their gross product. Thus, even when the GDP per capita increases, it has a positive and significant impact on the emissions. For cleaner countries, too, the results obtained are similar.
- *Urbanisation:* Model 1 depicts that urbanisation has an insignificant impact on GHG emissions, while Model 3

states that with the rise in urbanisation, dependence on energy resources increases. To bridge the gap between rising demand and the limited availability of energy resources, countries will start extracting and importing more exhaustible resources comparatively to clean sources of energy, thereby affecting the environment. Model 2 and Model 4 indicate that countries which are listed in the clean countries panel are mainly developed nations that can use efficient energy and still heavily rely on fossil fuels for industrial processes. While developed countries may implement more stringent environmental regulations and invest in cleaner technologies, the overall impact of urbanisation on carbon emissions remains positive and significant due to the sheer magnitude of energy requirements associated with urban lifestyles. Additionally, the complexity of urban infrastructure in developed countries can result in substantial carbon footprints.

- *Share Prices*: Model 1 depicts an insignificant relationship between share prices and GHG emissions, however, to our amazement, given the consumption of RE, share prices positively affect the GHG emissions. Increasing share prices are a result of higher production and energy use. As dirty countries have a major component of NRE in their energy mix, the result is justifiable despite the introduction of renewable sources. On the other hand, clean countries have increased the GHG emissions from Model 2 considering NRE to Model 4 considering RE. Higher production and energy consumption followed by higher share prices in the case of Model 4 contributes to an increase in GHG emissions. However, technological stagnation with the increase in energy demand and rising population leads to higher GHG emissions (Silva et al., 2021).
- *Trade Openness*: Given that exports form a major constituent of the GDP share in most developing nations, we observe a negative relation of trade openness with GHG emissions in both the models (1 and 3). Developing nations must conform with the rules and regulations of the importing countries and thus produce sustainably to reduce emissions. In contrast, clean countries have a negative relationship given the consumption of RE. Clean countries focus on sustainable practices by lowering both production-based and consumption-based emissions.

SUMMARY AND CONCLUSION

The present study has taken into consideration the influence of non-renewable and renewable sources of energy on the environment in the context of G21 nations from 2002–2022. The G21 nations were categorised into dirty and clean countries based on their ecological footprint scores. The countries that consume more natural resources than their capacity were included in the dirty panel and vice-versa for clean countries. The underlined variables i.e., GHG emissions, NREC, REC, urbanisation, stock prices, trade openness, FDI, and economic growth were selected to identify the nexus between the dependent and independent variables used in different models of the study. The GLS and GMM techniques were employed in the study. The findings of Model 1 revealed that non-renewable energy positively impacts GHG emissions in the case of the dirty countries panel. Since the majority of the countries are reliant on non-renewable energy for expansion of output leading to industrialisation. Further, GDP representing economic growth and trade openness, proxied by trade, significantly affect the emissions negatively. Lastly, FDI, urbanisation, and share prices do not significantly affect emissions.

The findings of Model 2 revealed that NRE positively impacts GHG emissions even in the case of the clean countries panel. However, this does not mean that the countries included in the clean panel have completely transitioned to clean sources of energy. The energy matrix is a combination of renewable and non-renewable forms of energy and thus, if countries consume NRE then the environment degrades. In addition, there exists a positive relationship between FDI, urbanisation, and share prices with GHG emissions. However, trade openness does not possess a significant relation with GHG emissions. The findings of Model 3 revealed that as the consumption of renewable energy increases in the case of the dirty countries panel, the GHG emission also increases. Climate change summits and various protocols related to environmental sustainability involve the participation of the developing nations which makes them include greener sources of energy in their energy grid. However, developing nations take time to transition from the NRE consumption economy to the RE consumption economy. The findings of Model 4 recognised that renewable energy has a negative relationship with GHG emissions in the case of the clean countries panel. Since the clean countries panel primarily comprises developed and richer nations, incorporates green sources of energy in their energy grid, this effectively reduces emissions, fostering environment quality.

POLICY IMPLICATIONS

- Government should impart knowledge, organise awareness and training programmes for the countries with the objective of give social recognition and acceptance to renewable and alternative sources of energy. Also, the government must initiate policies to promote companies performing social responsibilities and dedicating projects towards it (Basak, 2016).

- The countries must formulate stringent policies to curb carbon leakage and production-based emissions in their domestic territory. Effective conservation and environmental policies should be formulated in terms of high-tech clean coal-fired plants, establishing mechanisms to strategically reserve crude oil, promoting desulfurization, and implementing effective environmental monitoring and management techniques.
- Urbanisation leads to higher energy demand for residential and commercial purposes. Both the clean and dirty countries' panels should build efficient infrastructure and shift their focus to renewable energy in a phased manner.
- The stock market determines the financial health of an economy. Awareness among investors about corporate sustainability and the triple-bottom-line push the companies to work sustainably around the ESG framework to attract and retain investors and other stakeholders.
- The countries must implement Environmental Accounting (EA) to combat the harmful effects of carbon emissions. Prajapati and Shah (2024) have pointed out that disclosing EA information is a vital step towards carbon neutrality. Dash and Dey (2023) also support the idea of sustainable reporting.

LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

- The present study analysed the impact of REC and NREC on the environment. However, a comparative assessment of the impact of renewable and non-renewable energy sources on economic growth and the environment can be undertaken at both aggregate and disaggregate levels.
- Future studies should investigate the existence of long-term associations among the underlying variables in the study.
- There is a need to awaken global consciousness of achieving environmental sustainability. Consequently, further studies should encompass a broader array of countries to capture a larger and comprehensive contextual understanding of this discipline.

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