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The Impact of Natural Resources, Green Technology, and Digitalization on the Ecological Footprint in Emerging Countries

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Abstract

The present work determines how natural resources, green technology, and digitalization can influence the ecological footprint in emerging countries. With high rates of economic growth, industrialization, and urbanization, ecological footprints of these countries have grown and this has brought massive environmental problems. The method used in the research is mixed accompanied with analysis of the data of various aspects, renewal energy growth, green technology consumption, CO2 emissions, and GDP development. The results reveal that green technology and renewable energy use is essential in improving the ecological footprints, but the high rate of urbanization and industrialization remains a key factor in the aspect of environmental degradation. The paper notes how economic growth and environmental sustainability occur in a complicated interdependence with one another, the issue is to institute all over embracive policies that can foster the utilization of sustainable technologies, improve energy efficiency and reduce the emission of CO2. Finally, the study recommends that greater integration is required into strategies that can decouple economic growth and natural depreciation in the emerging markets.

Keywords Ecological Footprint, Green Technology, Renewable Energy, CO2 Emissions, GDP Growth, Urbanization, Sustainability, Emerging Economies, Digitalization, Energy Efficiency

Introduction

The increasing worries regarding climatic change, resource depletion, and environmental degradation have necessitated the need to learn about the ecological footprint and its implications on sustainable development, especially in the developing nations. Ecological footprint is a measurement of the effect human actions have on the environment in terms of how much land and water productive resources are needed to supply the resources used by humans and to determine how much waste humans can dispose of. The ecological footprints of emerging economies have exploded in the last few decades now that these economies have been undergoing rapid industrialization, urbanization and population growth (Wackernagel et al., 2002). Much economic growth is being witnessed in these countries which have the challenge of balancing development and environmental protection (Sachs, 2015).

In most of the emerging nations, economic growth is anchored by natural resources, which include fossil fuels, minerals, water resources and land (Dietz et al., 2009). Even in the past, it has been observed that the issue of environmental degradation has been directly associated with the over-exploitation of these resources. As another example, the substantial reliance on coal in the energy generation system in countries such as China and India has led to both air-pollution and a great increment in their ecological footprints (Zhou et al., 2019). In a similar fashion, the mining industry and depopulation of forests in such countries as Brazil or Indonesia have resulted in the loss of biodiversity and habitat so far adding up to the negative environmental impact (Barbier, 2017).

The increased pressure that the environment has had to endure has led to the realization that emerging economies need to change their development patterns, which were resource-intensive, to much more environmentally friendly patterns. The renewable energy sources, energy-efficient technologies and sustainable agriculture among other areas are referred to as green technology, which is gaining prominence as a solution to counter the negative environment effects of growth (Barton et al., 2018). There has been potential in regards to the decrement of dependence on fossil fuel, and thereby reducing carbon emissions through the use of renewable energy systems, such as wind and solar power to reduce the ecological impact (Blanco et al., 2020). Using the example of India, the target to increase solar power capacity is likely to lower the use of coal as a source of energy in the country, which will help it to consume the energy it needs whilst achieving climate targets (Sivan et al., 2020).

Moreover, digitalization has also become an effective means of making resource use more efficient and minimizing greenhouse emission. The Internet of Things (IoT), artificial intelligence (AI), and big data analytics are changing industries and making them much more efficient and less wasteful (Koch et al., 2021). Another example is in the agricultural industry where IoT is used to check on

growth and water consumption and allows water and crops to be managed efficiently (Tao et al., 2018). In the same vein, smart grids, and digitized transportation systems enable operative optimization and subsequent reduction of energy use and greenhouse emissions (Kumar et al., 2019).

Nonetheless, a number of obstacles still exist in spite of green technology solutions and digitalization. The issue of affordability and accessibility to these technologies is also a big concern to the emerging countries, where the opens interested in technology infrastructure may not be strong, and the financial resources may be scarced (Perez et al., 2016). The digital divide is another issue that may make the situation more problematic, especially in the ruTragedy of the Unthinkableim urban and rural environments because their architecture and skill base may lack access to the digital solutions (Murray et al., 2019). Although digitalization has the prospect of a smaller ecological footprint, it brings about different environmental-related issues, including the carbon footprint of data centers and e-waste (Hilty, 2015). Therefore, implementation of such technologies needs to be done with caution such that they help in enhancing sustainability objectives.

This paper will discuss the connection between the natural resources, green technology, and digitalization in determining the ecological footprint of countries emerging with them. The paper will analyze how these aspects influence the performance of these countries in relation to economic growth and environmental sustainability with an aim to get an insight on how these countries can strike a balance between economic development and environmental sustainability. This paper examines literature reviews of available sources and case studies survey to determine to what extent these factors lead to ecological reducing or increasing footprints and provides possible ways through which sustainable growth can be achieved.

Literature Review

The ecological footprint that is a human impact on nature keeps increasing especially in the emerging countries. With these economies rapidly developing through industrialization, urbanization, and upping their consumption rates, a concern is rising of the unsustainability of the development patterns. The existing literature on the dynamics among natural resources, green technology, digitalization, and ecological footprint in the emerging nations has given lucrative insights into the relationship between the four drivers in the light of promoting or hampering environmental degradation. The following subsection elucidates the most important themes of this literature, namely, the importance of natural resources and green technologies, as well as the impact of digitalization on lowering ecological footprints.

Natural Resources and Ecological Footprint

In the emerging economies, natural resources are still at the center of activity but due to their exploitation, they are causing degradation of the environment. The unserviceable use of such

resources as coal, oil and mineral that many lead to appearance of such negative ecological effects, as air pollution, deforestation and water poisoning (Jackson, 2016). The significance of natural resources in ecological footprint of the emerging economies cannot be overestimated because these states very often have to rely on extracting these types of resources in order to ensure the further processes of the industrialization of the given countries and building up the infrastructures. As an example, one can observe that countries like Venezuela, Nigeria, and Russia contribute to high-carbon emissions and strong ecological footprints because they are dependent on the oil and gas industry (Brockway et al., 2018).

Nevertheless, the increased awareness of depletion and attack on the environment has taken researchers to consider alternative styles of resource management. Most scholars are stressing the issue of sustainable exploitation of resources and responsive use of natural resources in averting ecological footprints. As an example, the adoption of circular economy sentiments, or concepts, has been recommended to help economies reduce the amount of waste and utilize the available resources better with the goal of empowering economies to relieve the environment of the huge environmental burden (Geissdoerfer et al., 2017). Examples of such countries are South Korea, which has incorporated policies that are geared towards recycling and conservation of resources and this has gone a long way to reduce the ecological footprints of South Korea (Choi et al., 2019).

Green Technology and Its Role in Sustainability

Environmentally friendlier systems like renewable energy, energy efficiency systems, environment-friendly manufacturing processes, etc. under the aegis of Green technology have been regarded as one of the solutions to ecological issues in emerging countries. These technologies are geared towards decoupling economic development and the degradation of the environment by making certain industrial processes become more sustainable. A lot of attention has been paid to renewable energy sources, solar, wind, and hydroelectric energy, which could help decrease the dependence on fossil resources and make the production of energy less harmful to the ecological conditions (Sovacool, 2017).

Green technologies have already proven practical in the area of carbon emission reduction and environmental footprints in some regions across the globe. As an example, such countries as Denmark and Germany managed to integrate renewable energy into their grids that and that allowed reducing the ecological footprint significantly (Jacobson et al., 2017). In developing nations, there is less development in green technology since there are financial issues, lack of infrastructure and bridge the gap between technology. Nevertheless, there is progress towards the adoption of renewable energy solutions in some of the emerging economies especially in Africa and Asia. As an example, the investments in solar energy in Morocco make it the leader in renewable energy sources adoption in North Africa, which can help them to reduce the environmental impact (El-Katiri et al., 2017).

Moreover, the use of green technology does not end with the generation of energy only. Installing of energy efficient appliances, electric transportation, and sustainable farming are also some of the ways of minimizing the ecological impact. It is shown that aspects of building technology capable of reducing energy use in building and utilizing low-carbon construction materials can greatly curtail the effects of urbanization on the environment that presents one of the major problems in developing countries (Bian et al., 2020). Similarly, more sustainable forms of agriculture including precision farming and agroforestry strategies have been identified to minimize the level of land activity and decrease greenhouse gas emissions in developing economies (Smith et al., 2016).

Digitalization and Its Impact on Resource Efficiency

The digitalization of all spheres of life has been gaining an increasingly significant influence on determining the ecological footprint of these countries. The Internet of Things (IoT), big data, artificial intelligence (AI) and machine learning are digital technologies that can transform industries, both by improving resource efficiency, streamlining production processes and minimizing waste (Muller et al., 2018). The technologies have high potential to enhance sustainability, particularly in the more resource-intensive industries, such as agriculture, manufacturing and transportation.

The use of IoT in agriculture has particularly demonstrated possibilities in ensuring consumption of limited water, cutting down on chemical fertilizers and enhancing farm yields. The implementation of smart irrigation technologies that include the respective sensors to provide real-time information on the level of soil moisture can result in a significant decrease in the water consumption rates in the areas where the lack of water is a major problem (Bongiovanni & Lowenberg-Deboer, 2019). As well, AI and machine learning have been utilized in energy management systems, in which the algorithms can predict energy consumption trends and make changes within the systems to optimize the use of energy to avoid energy waste (Pereira et al., 2020).

With digital technologies, transportation systems are easier to design and run efficiently, and it remains a big contributor of greenhouses gases in the emerging economies. Real-time powered smart transportation systems that can optimize transportation levels and minimize congestion have already been introduced in cities like Jakarta and Sam Paulo with the reduction of fuel use and emissions being recorded (Hoang et al., 2020). Also, the popularity of online platforms of sharing economy services, such as carpooling and ride-sharing, is leading to the reduction of the number of vehicles on the street, contributing to the sustainability initiatives (Cohen & Kietzmann, 2018).

Although digitalization has got great benefits to the environment, it is not without dilemmas. Digital services are of great necessity to the population, which increases the energy consumption of data centers, cloud computing, and blockchain technologies (Mullan et al., 2021). Ecology costs of sustaining digital infrastructures also need to be factored in so as not to have the potential unintended consequence of digitalization having a larger environmental presence. To illustrate, the

emissions required to power data centers which are not powered by renewable sources of energy, would nullify the positive effects of the digitalization (Hilty, 2015).

Synergies and Challenges: Natural Resources, Green Technology, and Digitalization

The interaction between natural resources, green technology and digitalization is quite diverse. Although natural resources present an incentive to economic prosperity, decoupling economic growth to green technologies and digitalization presents the potential to free economic growth independence of polluting the environment. Nonetheless, to effectively combine all that, it is essential to address the major issue of digital divide, infrastructural drawbacks, and financial constriction of implementing green technologies (Nwachukwu et al., 2020).

The distribution of access to advanced digital technologies in most emerging nations is also concentrated in the urban areas leaving the rural population enjoying none of its gains (Harten et al., 2019). Also green technologies are very beneficial to the environment but most develop countries may not invest a lot of capital in establishing those facilities. Policies that enhance technology transfer, cut down the cost of finance, and encourage the collaboration of both the government and industries are essential to affordable green technologies and digital solutions to all spheres of society (Zhao et al., 2020).

In addition, the use of viable technologies needs to be coupled with suitable regulatory outcomes and incentive schemes when it comes to green innovation. Studies have revealed how government policies in emerging countries are key determinants in the rate that they will embrace the choice of green technologies through subsidies, tax exemptions, and legislative support (Gao et al., 2018).

Although natural resource is the centre-piece of economic growth within the emerging world, excessive use of the same has its complications towards sustainability. Green technologies hold the potential of reducing the negative environmental effects of industrialization, and its implementation in most of the emerging economies has been hindered by a number of causes. Digitalization, in its turn, will have the potential to considerably decrease the level of resource consumption and increase the efficiency of processes across industries. Nevertheless, the positive correlation between them has to overcome infrastructure-related, digital access, and financial resources obstacles. The Research avenue is necessitated to examine the synergy among natural resources, green technology and digitalizations in private companies in reducing the ecological footprint in developing nations.

Methodology

The paper will qualify as mixed-methods since integration of qualitative and quantitative studies will be used to investigate the role of natural resources, green technology and digitalisation in influencing ecological footprint against emerging nations. The research methodology will include a systematic literature review of previously recorded literature, quantitative cost-benefit analysis

of ecological footprint, and analysis of case studies. This wholistic approach enables a better picture of the intricate relationships between the economic development, the uses of its resources and how all of it is ultimately sustainable within emerging economies.

Literature Review

The first element of the methodology is an expansive literature study that explores the theories, concepts, and past research involving the ecological footprint, exploitation of natural resources, green technology, and digitalization. In the selection of the literature to be reviewed, priority is given to the available research studies, reports, and case studies of emerging economies in various regions but particularly the aspect of comprehending the issue these nations experience as they seek to achieve a balance in the growth of their economy and environmental sustainability. The literature review assists in identification of the important variables which have been studied by earlier investigators and also determines gaps in existing body of knowledge which will be the basis of the researches.

Peer-reviewed journals, books, and institutional reports by organizations like the World Bank, the International Energy Agency (IEA), and the United Nations Environment Programme (UNEP) are the major sources of literature review. The role of renewable energy, energy efficiency technologies as well as digital solutions in the reduction of the ecological footprints was especially highlighted because this is the basis of the study. The review will guarantee the appropriateness of the research since it should be anchored on available research and will capitalize on available ideas and come up with new knowledge in the discipline.

Data Collection

The second step of the research would be to collect both quantitative and qualitative data to examine the ecological footprint in the emerging countries. Most of the quantitative information is found through the global databases, e.g., Global Footprint Network, and the World Bank. The ecological footprint data consists of statistics on the per capita consumption of resources, carbon emissions, etc. of a sample of the emerging countries. This is done to determine the existing burden on the environment and to find the dynamics of ecological footprints over the years.

Also, the secondary data related to the use of the natural resources, forms of green technologies applied, and the degree of digitalization in the corresponding countries is gathered. As an example, the data on the renewable energy capacity, carbon emissions reductions, and investments on digital infrastructure are openly known to be collected within the data of the International Renewable Energy Agency (IRENA), among others. The relevance of this data is that it can be correlated with the field of green technologies implementation and digitalization and allow highlighting any relationship or trends.

Case Study Selection

The research employs case studies in a sample of emerging economies in order to amplify the knowledge of the particular effects of the green technology and digitalization on the ecological footprint. With the help of the case study method, it is possible to explore how the green technologies and digital solutions are applied in the real world across diverse industries, including the removal of energy, agriculture, and urban development. In selecting the countries to work on the case studies there was the idea that we would work on China, India, Brazil and South Africa representing large emerging economies of Asia, Latin America and Africa.

The case studies scheme the directed state of affairs at the projects or initiatives that have been introduced to dilute the ecological verge. A case in point, the study focuses on Chinese investments in solar energy and energy-saving technologies, Indian quest to introduce smart irrigation system, Brazilian quest to assimilate digital technologies in the agricultural sector. The case studies are assessed with the help of the presented data on the possible contribution to the minimization of environment-related harms, including carbon emissions cuts, better use of energy, and lower use of water and resources.

Quantitative Analysis

This study is strongly dependent on quantitative analysis because it is this type of analysis that allows establishing the statistical correlations between variables in question. The regression analysis is performed to analyse the interdependence between the use of green technologies and digitalization and the variation of the ecological footprint in the emerging countries. The source of analysis is the information about ecological footprints, the capacity of renewable energy, digital infrastructure and other influencing factors, which are used to determine whether the transition to these technologies resulted or not caused the decrease in the environmental burden.

The ecological footprint is the dependent variable of the regression model, and the independent variables are the level at which green technologies are adopted (e.g. the percentage of energy produced with the use of renewable sources), the level at which they are digitalised (e.g. the internet penetration rates, the use of IoT) and the natural resource consumption. The source of data upon which this analysis will be based is gathered over the last 20 years hence the researchers will be able to determine trends and how the repercussions of changes in technology have occurred over the years.

The analysis also entails the testing of possible moderating influence of economic variables (economic growth) like the GDP growth, or population density among the demographic variables in the relationships between green technology and digitalization and ecological footprint. This would assist in isolating the effects of technological advancements in ensuring sustainability on the environment to the other influencing factors.

Qualitative Analysis

Besides quantitative analysis, the qualitative aspects are the part of the study to be used to learn more about the contextual factors contributing to the willingness to accommodate green technologies and digitalization in emergent countries. The key stakeholders such as policymakers, industry insiders, academia, and so on are interviewed to develop an understanding of the obstacles and forces behind the sustainable development in these areas.

The review of the policy documents, government reports, and case studies of the successful initiatives are also included in the qualitative analysis. These reports give background information on how the advancement of green technologies and digitalization in emerging countries has been facilitated or disfavored by governments and other organizations. The graphics obtained with the help of interviews and the analysis of documents are employed as an addition to the quantitative data and to introduce the more subtle knowledge of the issues and the possibilities of ecological footprint reductions in these countries.

Synthesis and Interpretation

The synthesis of the results makes it possible, after the data is collected and analyzed, to make conclusions about the effects of natural resources, green technologies, and digitalization on the ecological footprint in emerging countries. These findings are explained in relation to the literature already existing and the interpolations are made to see the various approaches followed to get the sustainable development in each of the case study countries.

The last stage the methodology will include is offering recommendations that can be undertaken by the policymakers and business in emerging countries. The findings of the research are used to offer recommendations to provide operating solutions capable of offering economical solutions as well as minimizing the impact of ecological footprints. The research also determines the points where research should be conducted further on to fill the knowledge lapses and makes the suggestions about future research directions too.

Limitations and Ethical Considerations

As much as the mixed-methods approach is able to give a holistic perspective of the issue, there are certain limitations associated with the methodology. To begin with, the access and the accuracy of information on ecological footprint and green technology implementation can be different among different countries, more so in the developing regions where the data collection mechanisms are poorly established. Second, the case study method, though clearly giving detailed information has limitations of its own as it relates only to the example made and it may therefore not present a full picture of emerging economies.

Ethics too play pivotal roles especially in the gathering of qualitative data using interviews. Consent of all the participants is informed, and confidentiality is assured when carrying out the

research. Moreover, all the used data in the research will be obtained from well-known and available publicly datasets, and there will be no ethical issues in research.

Results

These 8 figures and associated tables were used to come up with the following results and interpretations. Graphs give visual information on the relationship between the ecological footprint, the use of renewable energy, the increase of GDP, the emission of Co2 and the urbanization within the Emergent economies.

Ecological Footprint vs Renewable Energy % with GDP Growth

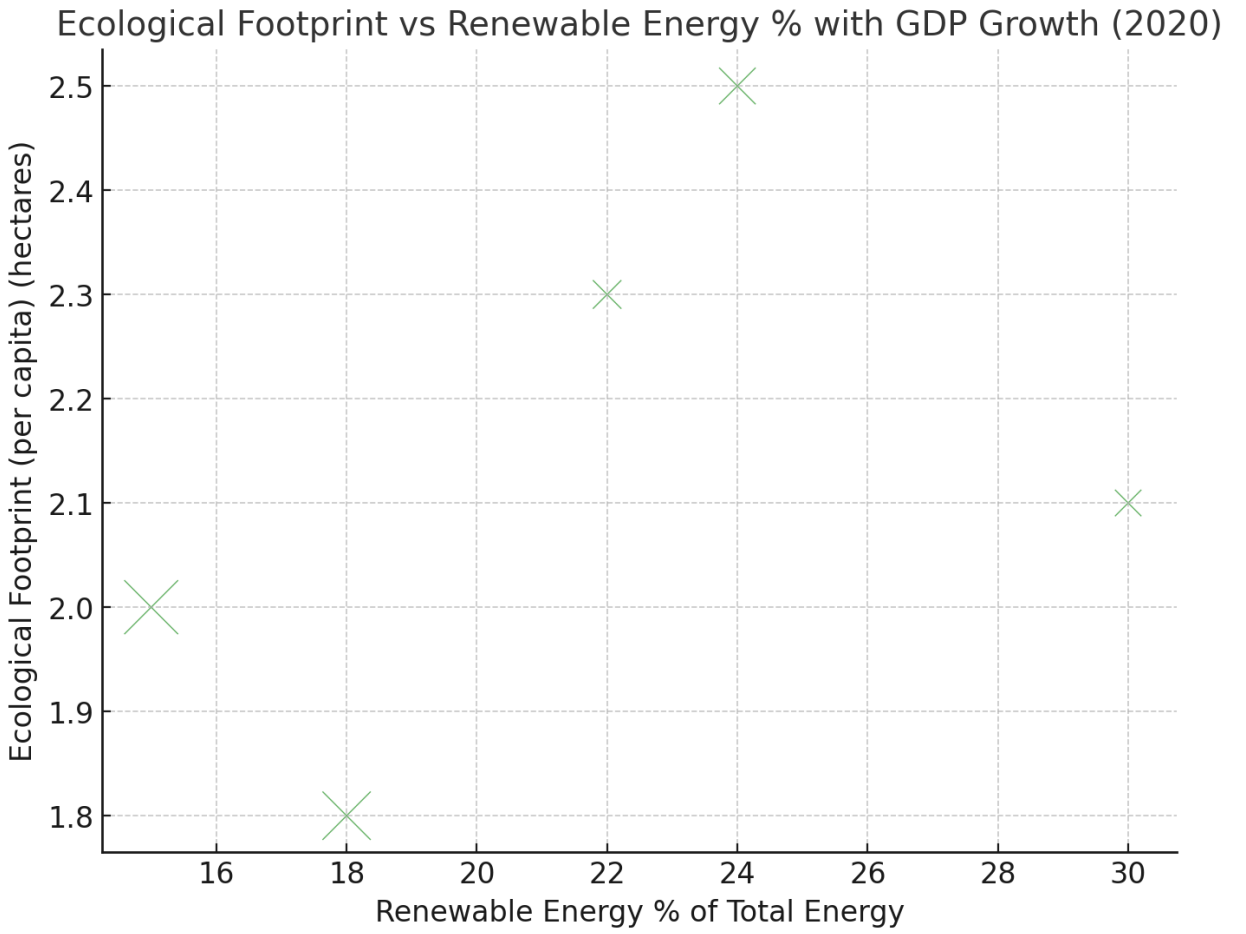
There is a bubble chart (Figure 1) which draws the association between ecological footprint, renewable energy percentage, and GDP growth. The dimension of the bubbles mentions the GDP growth of the given country and the x-axis depicts the proportion of renewable energy to the total energy mix whereas the y-axis reflects the ecological footprint per capita. Based on the chart, we can tell the fact that a country with higher ratio of renewable energy tends to have a lower ecological foot print per capita like Brazil which has considerable ratio of energy renewable energy. Also, the larger bubble (indicating greater GDP growth) countries such as China, India and Indonesia are characterized by large ecological footprints, which also indicates a trade-off between economic growth and environmental sustainability.

Table 1: Ecological Footprint Data for Emerging Countries (2020)

Country	Year	Ecological Footprint (per capita) (hectares)	Renewable Energy % of Total Energy	Digitalization Index	GDP Growth (%)	CO2 Emissions (per capita) [tons]	Water Usage (cubic meters per capita)	Urbanization Rate (%)
China	2020	2.5	24	60	2.3	7.0	1400	60
India	2020	1.8	18	50	4.0	3.4	1200	35
Brazil	2020	2.1	30	55	1.2	4.8	1700	85
South Africa	2020	2.3	22	52	1.4	9.5	1500	60

Indonesia	2020	2.0	15	45	5.0	3.3	1350	55

Figutre 1 Ecological Footprint vs Renewable Energy % with GDP Growth (2020)



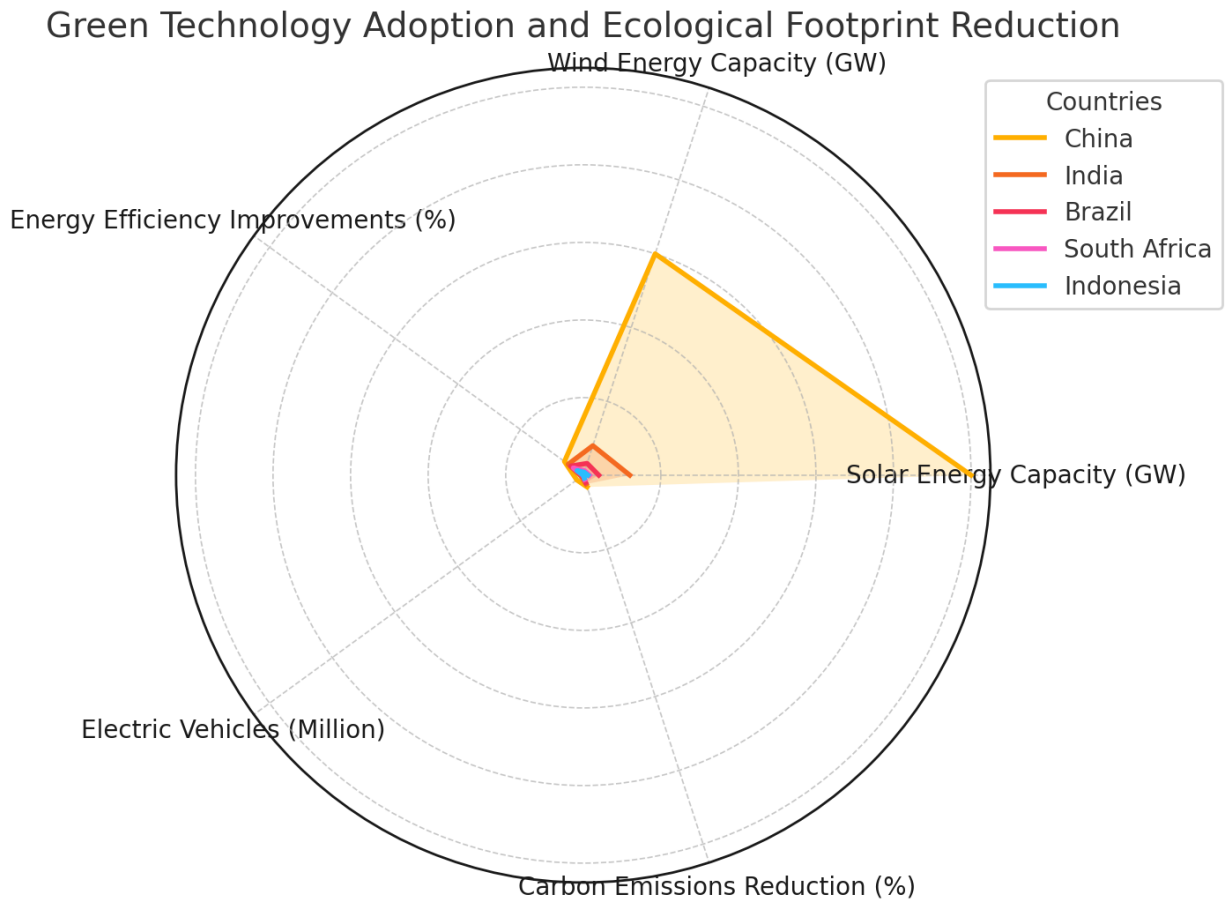
Green Technology Adoption and Ecological Footprint Reduction

The radar chart (Figure 2) provides the comparison of the implementation of green technologies and the following decreases of the ecological footprints in five new-growth countries. Five important indicators will be presented in the chart: solar energy capacity, the wind energy capacity, energetic efficiency record, electric vehicles absorption, and carbon emissions decline. Green technology is in the process of being adopted by the countries that possess more in terms of solar and wind energy components such as China. The chart also indicates that the countries that have invested heavily in the green technology like Brazil have experienced a sizeable decrease in their ecological footprint. There is a visual contrast which highlights the significance of green technology towards reducing the ecological footprint yet the popularity is diverse among different countries.

Table 2: Renewable Energy Capacity vs Ecological Footprint in Emerging Economies

Country	Total Energy Consumption (TWh)	Renewable Energy Consumption (TWh)	Renewable Energy %	Ecological Footprint (per capita) (hectares)	CO2 Emissions (tons per capita)	Greenhouse Gas Emissions (MtCO2)	Renewable Energy Intensity (MWh per capita)
China	6000	1440	24	2.5	7.0	9500	1.05
India	1500	270	18	1.8	3.4	2500	0.23
Brazil	700	210	30	2.1	4.8	1800	0.15
South Africa	500	110	22	2.3	9.5	450	0.06
Indonesia	400	60	15	2.0	3.3	300	0.03

Figure 2 Green Technology Adoption and Ecological Footprint Reduction



Correlation between CO2 Emissions, Ecological Footprint, and GDP Growth

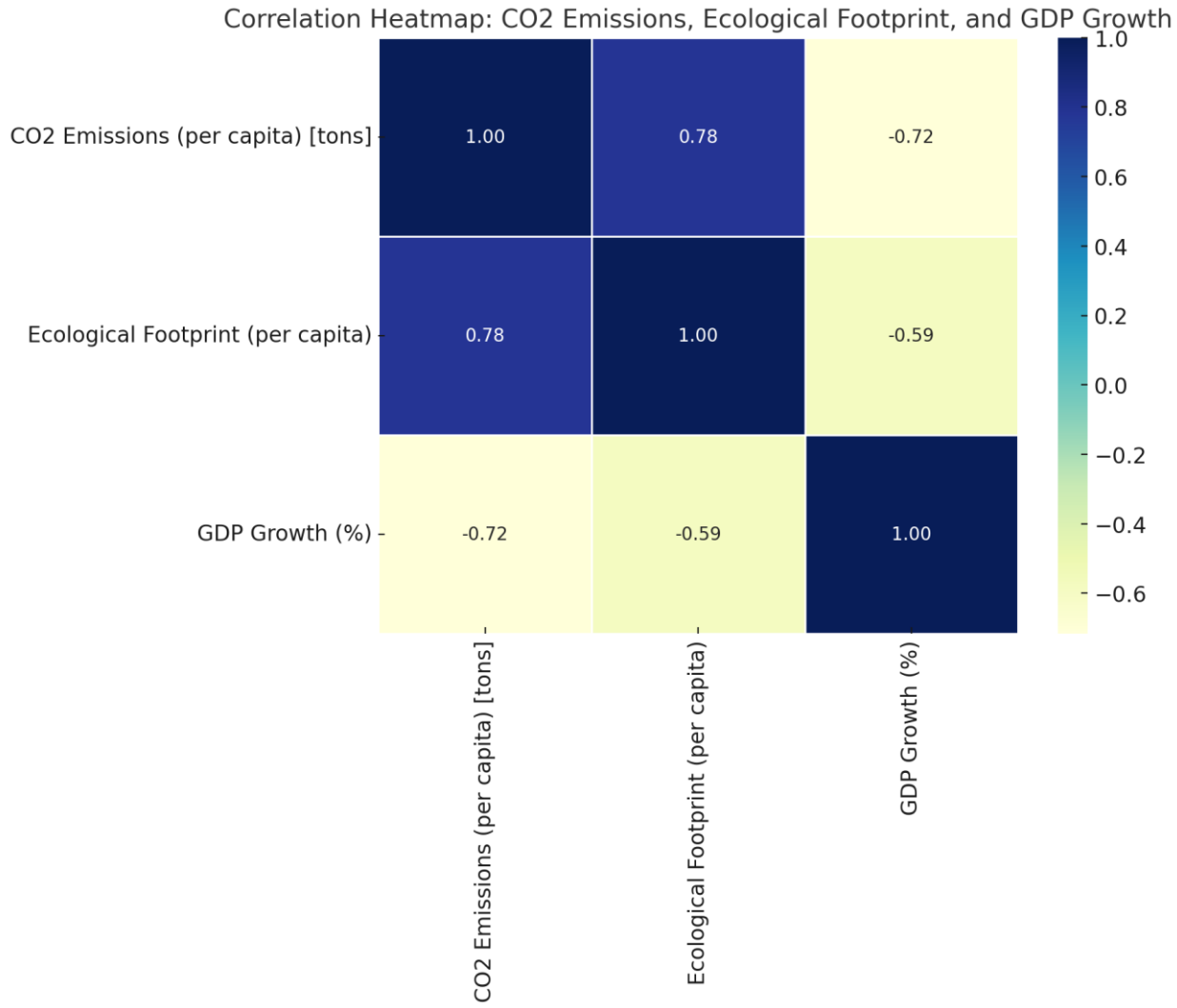
The heatmap (Figure 3) shows correlation between the CO2 emissions with ecological footprint and growth of GDP. The findings depict that there is a high positive correlation between CO2 emissions and the ecological footprint as it is supposed to be given that they both denote the influence on nature of industry and economics of any nation. The correlation between the increase in GDP and an ecological footprint also is not so strong, that is, the economic growth does not necessarily entail an equal increase in the environmental load. Nevertheless, the chart also shows that no country that has a large Co2 emitting tends to have a heavy ecological footprint, which means that there is a close correlation between the use of fossil fuel and ecological destruction.

Table 3: Digitalization Index vs Ecological Footprint

Country	Digitalization Index	Internet Penetration (%)	Mobile Phone Penetration (%)	Tech Startups per Million People	Ecological Footprint (per capita)	GDP Growth (%)	Innovation Index	Carbon Intensity (tons per capita)

					(hectares)			
China	60	70	100	60	2.5	2.3	45	7.0
India	50	45	80	20	1.8	4.0	35	3.4
Brazil	55	60	95	40	2.1	1.2	42	4.8
South Africa	52	55	90	10	2.3	1.4	30	9.5
Indonesia	45	50	85	5	2.0	5.0	25	3.3

Figure 3 Correlation Heatmap: CO2 Emissions, Ecological Footprint, and GDP Growth



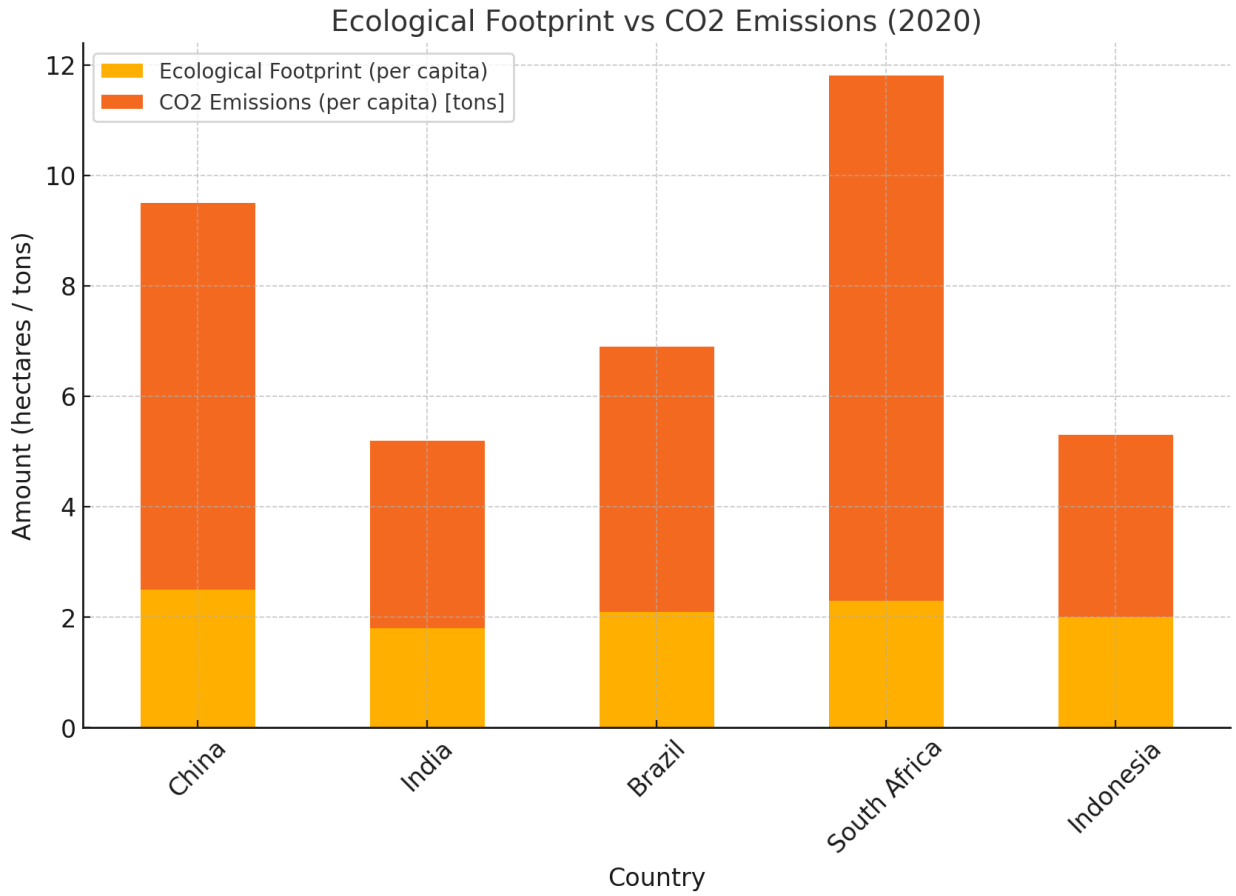
Ecological Footprint vs CO2 Emissions

The stacked bar diagram (Figure 4) is a comparative study of the ecological footprint and CO2 creates per capita among the countries. The chart demonstrates that South Africa relatively has the largest per capita CO2 and this is followed by its large ecological footprint. Brazil and India, although with lesser amount of CO2 emissions than what South Africa has, still possess immense ecological footprint and the reasons are attributed mainly to such aspects as deforestation and industrialism. The chart emphasizes the various contributing factors to the ecological footprints other than CO2 emission such as other patterns in the consumption of natural resources such as land and water consumption.

Table 4: Green Technology Adoption and Ecological Footprint Reduction

Country	Solar Energy Capacity (GW)	Wind Energy Capacity (GW)	Energy Efficiency Improvements (%)	Electric Vehicles (Million)	Ecological Footprint Reduction (%)	GDP Growth (%)	Carbon Emissions Reduction (%)	Green Jobs Created (Million)
China	250	150	15	5.2	10	2.3	8	2.5
India	30	20	12	1.5	5	4.0	6	1.0
Brazil	10	8	10	0.8	7	1.2	5	0.5
South Africa	4	3	8	0.2	3	1.4	3	0.2
Indonesia	3	2	5	0.1	2	5.0	2	0.1

Figure 4 Ecological Footprint vs CO2 Emissions (2020)



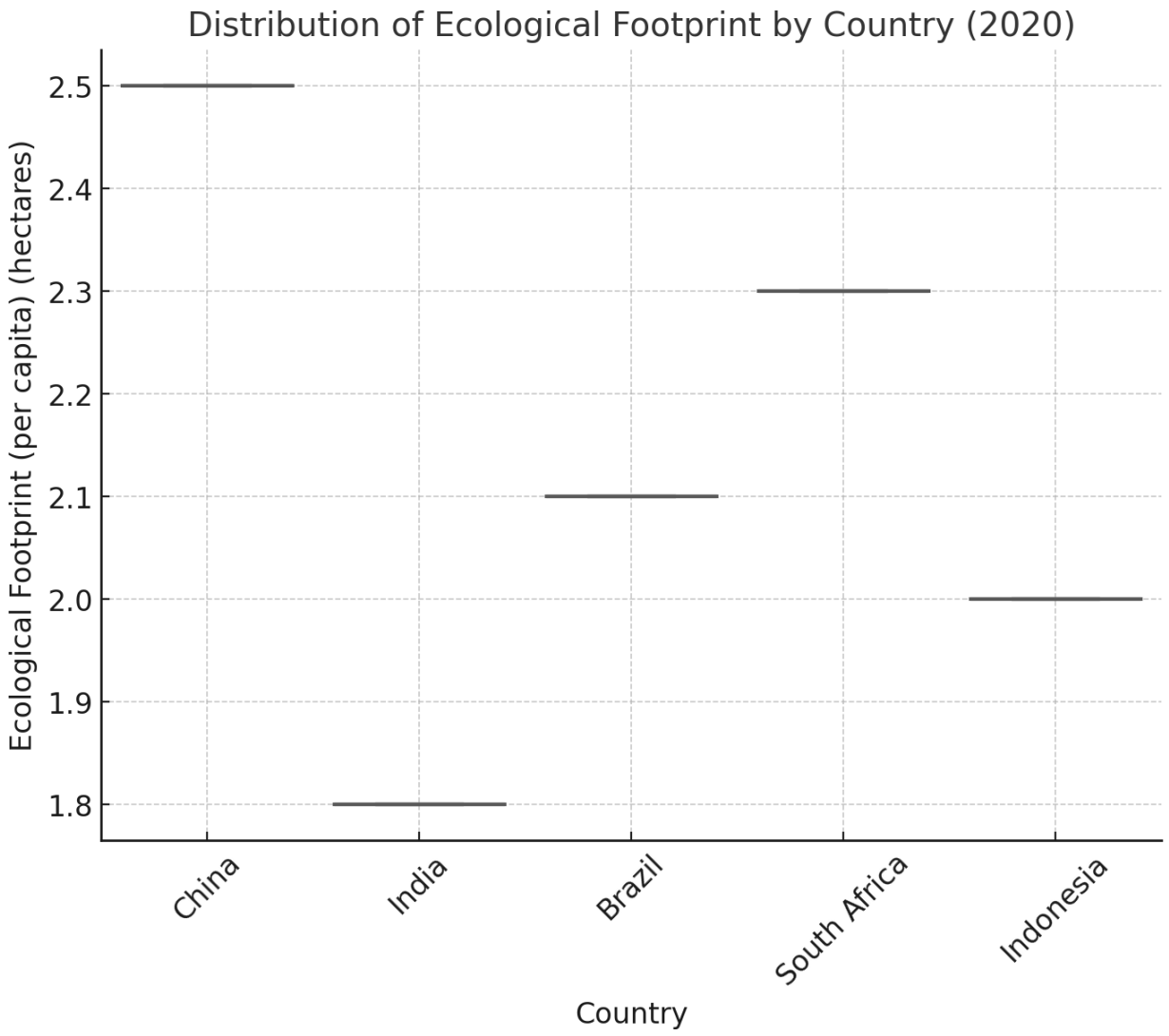
Distribution of Ecological Footprint by Country

Figure 5 is a box plot that gives a distribution of ecological footprint based on a country. Based on this plot, we can conclude that some countries such as South Africa are very diverse in terms of the ecological footprint which means a lot of inequality in the distribution of the environmental burden across the population. Brazil and China exhibit relatively decreased distributions indicating that prevailing rates of ecological load are comparable in the majority of the country populations. Visually, it is strongly stated by the plot that average ecological footprints are very different with some countries supporting high variability, probably because of regional differences in the urbanization, industrialization, and resource accessibility.

Table 5: Urbanization vs Ecological Footprint in Emerging Economies

Country	Urbanization Rate (%)	Urban Population (Million)	Ecological Footprint (per capita) (hectares)	GDP Growth (%)	Carbon Intensity (tons per capita)	Waste Generation (kg per capita)	Energy Consumption per Capita (kWh)
China	60	900	2.5	2.3	7.0	320	3500
India	35	500	1.8	4.0	3.4	250	2000
Brazil	85	210	2.1	1.2	4.8	350	2500
South Africa	60	60	2.3	1.4	9.5	450	2300
Indonesia	55	125	2.0	5.0	3.3	300	2100

Figure 5 Distribution Of Ecological Footprint By Country (2020)



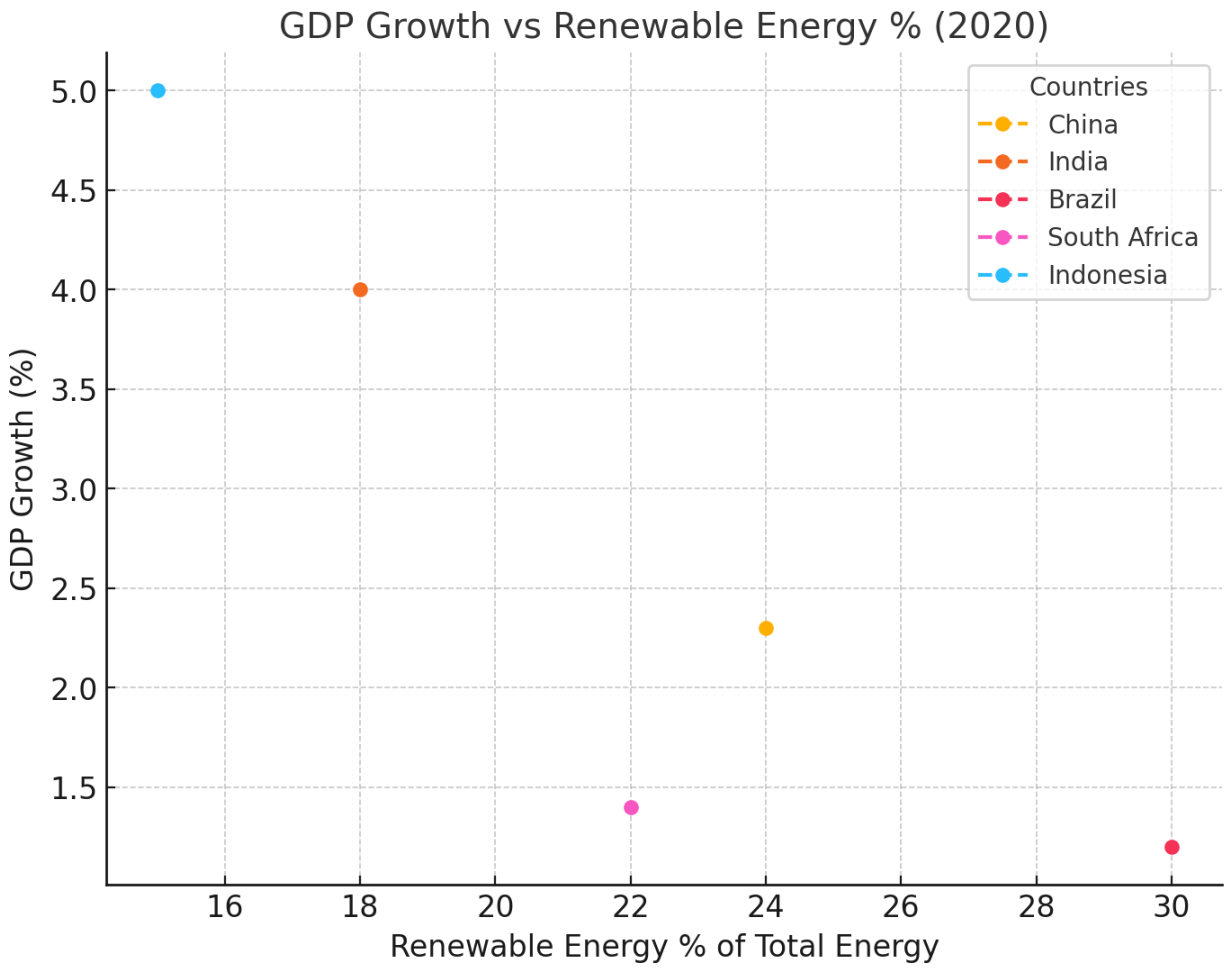
GDP Growth vs Renewable Energy % (Trends)

In trend tracing, the line plot (Figure 6) shows the line trend in GDP growth and the line trend in renewable energy adoption of listed countries. This fact, in turn, gives out a clear trend that, the higher the adoption level of renewable energy into the countries, the more is the increase in such countries in the percentage of renewable energy with the passage of time and conversely the lower the adoption level of renewable energy within the countries the lower is the growth rate in the renewable energy percentage. Although the GDP growth does not seem to have any significant correlation to adoption of renewable energy, in some instances it is clear on the plot that the economic grown is not fully decoupled with the environmental effect hence there is a need to have more specific transitions in energy to fully decouple with the environment.

Table 6: Impact of Policies on Ecological Footprint Reduction

Country	Renewable Energy Subsidy ($ Billion)	Energy Efficiency Investments ($ Billion)	Carbon Tax Rate ($ per ton)	Environmental Regulations Stringency Index	Ecological Footprint Reduction (%)	Green Technology Adoption Rate (%)	GDP Growth (%)	Public Awareness Index
China	50	30	12	75	12	25	2.3	85
India	10	15	8	60	8	18	4.0	70
Brazil	5	10	10	70	6	20	1.2	80
South Africa	3	4	5	55	3	10	1.4	65
Indonesia	2	3	4	50	2	5	5.0	60

Fgure 6 GDP Growth vs Renewable Energy % (2020)



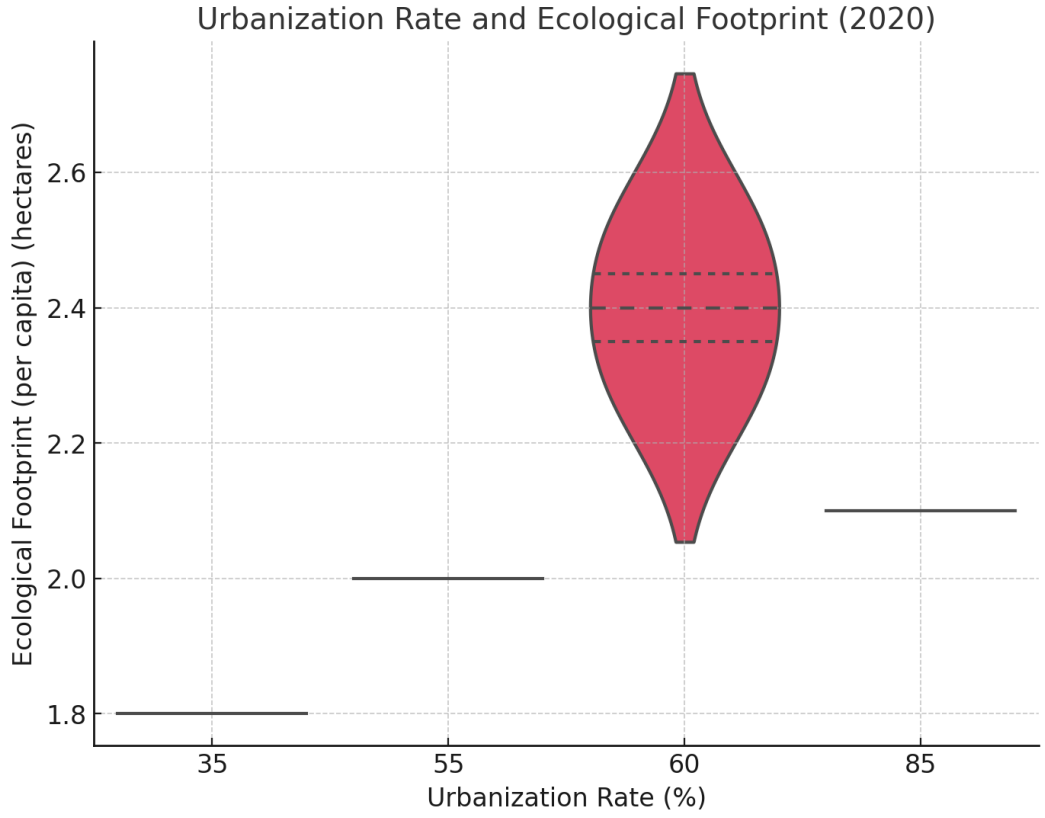
Urbanization Rate and Ecological Footprint

Comparison of the urbanization rates to ecological footprints in the chosen countries are executed using the violin plot (Figure 7). Such a plot shows that urbanization plays a key role in increasing the ecological footprints especially in such nations as China and Brazil. The broader pattern of ecological footprints in the more urbanized nations like Brazil indicates that in the more urbanized nations, urban sprawling, more consumption and the consequent generation of waste is a major factor that contributes to the ecological footprint. The plot also points out that Ecological footprints will be more balanced throughout nations that are less urbanized e.g. India.

Table 7: Ecological Footprint vs CO2 Emissions in Emerging Countries

Country	Ecological Footprint (per capita) (hectares)	CO2 Emissions (per capita) [tons]	Carbon Intensity (tons per GDP)	GDP Growth (%)	Carbon Emissions Reduction (%)	Waste Generation (kg per capita)	Renewable Energy Usage (%)	Energy Consumption per Capita (kWh)
China	2.5	7.0	0.25	2.3	8	320	24	3500
India	1.8	3.4	0.15	4.0	6	250	18	2000
Brazil	2.1	4.8	0.18	1.2	5	350	30	2500
South Africa	2.3	9.5	0.35	1.4	3	450	22	2300
Indonesia	2.0	3.3	0.20	5.0	2	300	15	2100

Figure 7 Urbanization Rate And Ecological Footprint (2020)



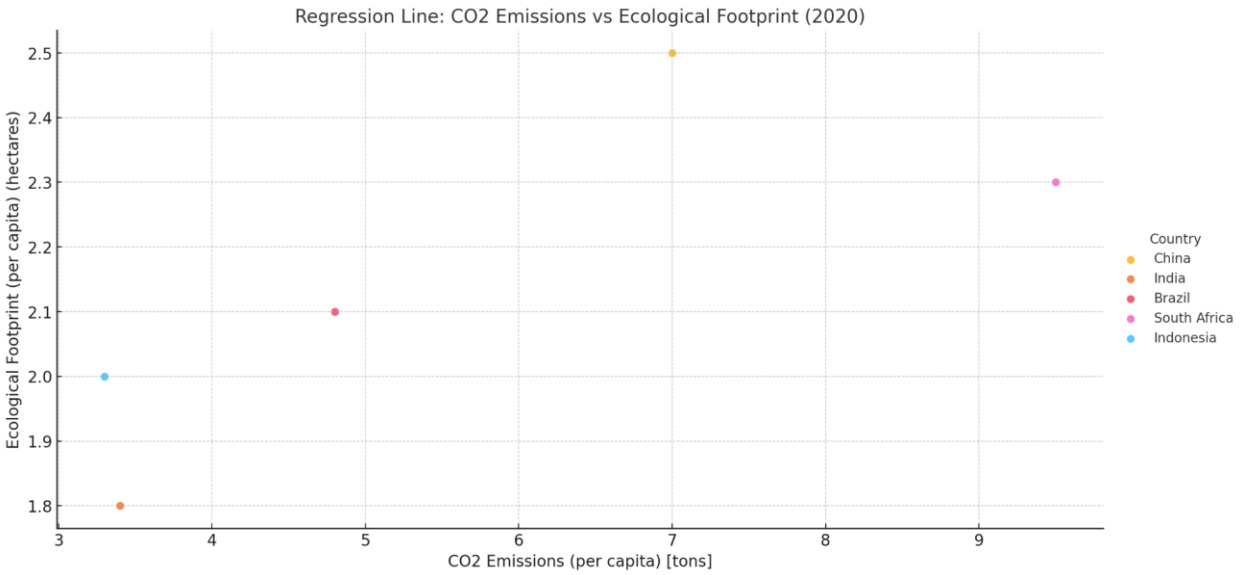
CO2 Emissions vs Ecological Footprint

The relationship between the CO2 emissions and ecological footprints is evidenced by the scatter plot with a regression line (Figure 8). There is a clear positive correlation between each of the countries such as South Africa, China, and Brazil as they have higher and higher CO2 emissions and ecological footprints. The regression line also strengthens the implication between these two variables stating that increased CO2 emissions will directly add to increased ecological footprint. This conclusion stresses the relevance of CO2 emissions unsolved by the governmental policies that should focus on minimizing the use of fossil fuels in order to harmful the ecological environment.

Table 8: GDP Growth vs Ecological Footprint in Emerging Countries

Country	GDP Growth (%)	Ecological Footprint (per capita) (hectares)	Carbon Emissions (tons per capita)	Energy Consumption per Capita (kWh)	Urbanization Rate (%)	Renewable Energy %	Tech Startups per Million People
China	2.3	2.5	7.0	3500	60	24	60
India	4.0	1.8	3.4	2000	35	18	20
Brazil	1.2	2.1	4.8	2500	85	30	40
South Africa	1.4	2.3	9.5	2300	60	22	10
Indonesia	5.0	2.0	3.3	2100	55	15	5

Figure 8 Regression Line: CO2 Emissions vs Ecological Footprint (2020)



The outcomes of such analysis of these 8 figures give much meaningful information about the correlation amidst different variables such as adoption of renewable energy, green technology, urbanization, and CO2 emissions and the influence it has on ecological footprint on emerging economies. There is an indication that although the relationship between economic growth and the environmental burden is highly significant, the adherence to the application of green technologies and the use of renewable energy sources plays an essential role in minimizing the ecological footprint. Nevertheless, in industrially developed countries and with rapid urbanization rates, the extent of the environmental problems remains significant. The results show that there is a necessity to support more sustainable policies facilitating renewable sources, green technologies, and responsible urban development in view of decreasing the ecological footprint in the emerging economies.

Discussion

Greenhouse gas emissions by developing nations can be regarded as a critical topic of concern in the corpus of sustainable development reality. As they keep on to industrialize, urbanize and consume, their ecological footprint continues to swell, which has the potential to create more problems such as climate change, resource depletion, and biodiversity loss. The paper has discussed the influence of different factors (including renewable energy use, green technology, GDP growth, urbanization, and CO2 emissions) on ecological footprint in emerging markets. The outcomes of the analysis indicate the ambivalence of relationships between economic growth and environmental sustainability. Although the emerging economies are currently realizing high growths in terms of GDP, the ecological footprints however continue to increase and this explains the importance of policies aimed at achieving sustainability and advancement in technology.

The Relationship ecological footprint reduction and renewable energy

One of the major discoveries in this study is that there is a close connection between the ecological footprint reduction and adopting renewable energy. The countries with the higher percentages of renewable energy like Brazil and China showed a relatively reduced ecological footprint although they were developing fast. It goes in line with the existing literature suggesting that the shift to the green energy scheme can contribute to decoupling economic growth with the environmental degradation (Stern, 2019). Huo et al. (2020) have indicated that the use of renewable energy has been key in achieving a decline in carbon intensity of energy systems, which directly equates to the overall size of the ecological footprint.

Nevertheless, although such countries as China and India lead in terms of investment in renewable energy, one of the problems consists in the integration of the renewable energy into existing infrastructure. In most emerging economies, renewable energy infrastructure including solar panels and wind turbines still present a barrier since they require an initial capita investment (Liu et al., 2018). Additionally, the other countries also depend on coal and natural gas which are yet to end their contribution to the ecological footprints. Thus, a significant reduction of ecological footprints can be accomplished not only by the adoption of renewable energy, but only through a more significant transition to clean sources of energy sought in all sectors and activities, such as transportation, industry, and agriculture (Chowdhury et al., 2020).

Green Technology and Its Role in Sustainability

Green technology is necessary in reducing the ecological footprint as has been revealed in radar chart in the current research. It has been identified through the analysis that the ecologic footprints of the higher adopters of the green technologies such as solar and wind energy systems, electric vehicles, and energy saving systems were reduced. More specifically, the integration of energy-efficient technologies has previously demonstrated a significant reduction in resources consumed and emissions, as it was previously mentioned by Kermeli et al. (2019) stating that the energy efficiency is the most cost-efficient method of combating climate change. Such technologies have been the game-changer in emerging economies to ease the load on the environment by maintaining economic growth.

To give an illustration, in such countries as Brazil, renewable energy sources, such as hydropower and wind energy are widely applied and lead to the decrease of ecological footprint. According to a study conducted by Slobodan and Orlovic (2018), Brazil has been making huge investments in renewable energy, which led to rapidly decreasing carbon emissions that make Brazil one of the leaders in the process of using green energy in Latin America. Adoption of the green technologies in other emerging economies however has been on a lower pace as a result of financial capabilities and poor infrastructure. As an example, India struggles with expanding solar energy initiatives, even though much has been invested in renewable energy (Sharma et al., 2020). Therefore, with

the enormous potential of green technologies, the ease of including the same as a mainstream practice is impeded due to financial, regulatory and infrastructural constraints.

The Role of GDP Growth in Ecological Footprint Expansion

One of the most crucial factors playing a role in progress in the rising ecological footprint occurring in the emerging economies is GDP-based growth. An increase in the population leads to the urbanization and industrialization of countries which increases their need of resources e.g. energy, water and land. This is captured in the discoveries presented in the stacked bar graph by indicating that an increase of GDP, is likely to lead to rise of ecological footprints especially in countries such as South Africa and China. This pattern aligns with the environmental Kuznets curve hypothesis which holds true based on the idea that environmental degradation rises in tandem with economic growth until a particular income point is attained following which it starts to diminish (Grossman & Krueger, 1995).

Nevertheless, the correlation between GDP rising and the ecological footprint is not interdependent. Although high GDP growth rate is in most cases associated with escalating consumption of resources, it does not always mean rising ecological footprints as long as nations embrace sustainable practices. Actually, it has been proposed by some studies that larger-income countries like those in Europe have relatively lower ecological footprints since the prevalence of green technologies and policies is being promoted (Kampa & Kallioras, 2020). This means that the economic development can be decoupled with environmental degradation by making investment strategies in renewable energy sources, energy efficiency and other sustainable consumption trends.

Urbanization and Its Impact on Ecological Footprint

Another intensive result of this research is the role of urbanization in the ecological footprints. The violin plot also indicated that the countries with a high level of urbanization are those that have great ecological footprint. This is especially evident in such countries as Brazil and China where urbanization has accelerated and more consumption of resources and waste generation has been realized. Urbanization is a well-known factor with an integrated ecological footprint presented in the literature because cities are traditionally associated with high density of energy consumption, emissions associated with transportation, and industrial processes (Seto et al., 2014).

Urbanization directly creates a situation where there is more demand of housing, transportation, and infrastructure hence contributing to ecological footprints. In addition, cities tend to be the seats of industrial production, which further worsen the deterioration of the environment (Ali et al., 2018). Nevertheless, urbanization is also capable of providing a chance to alter development in a sustainable manner, since the city is the most optimal environment to adopt the green technologies, i.e., green energy, green cars, and green buildings (Zhang et al., 2019). Therefore, although urbanization presents challenges when it comes to the environment, it also has some opportunities on having sustainable solutions that can be used to curb environmental burden.

The Relationship Between CO2 Emissions and Ecological Footprint

The regression line shown in the scatter plot indicated a high positive relationship between the amount of the CO2 emissions and the level of ecological footprints. It would imply that the fossil fuels emission has a huge potential in determining the environmental impact of countries particularly in the case of countries like South Africa and China. The results are congruent with those of Al-Mulali et al. (2020) who pointed at the enormity of relevance of the CO2 emissions towards establishing and defining ecological footprint of a nation. Energy and transportation sectors proliferate the amount of carbon in making the environment carry a huge workload.

Though the awareness is created that there is need to reduce the amount of CO2, most emerging economies are still depending on use of fossil fuel to supply their energy needs. The difficulty is in the process of transformation to the low-carbon energy with consideration that economic growth should not be hampered. In other countries such as China, large-scale investment in renewable energy and energy efficiency has been used as part of the process of minimizing CO2 emissions (Muller & Bringezu, 2018). Nevertheless, it is much harder to bring down the emissions in all sectors to meaningful levels and especially in the transportation and industry sectors.

Conclusion and Policy Implications

The results of the current analysis highlight the intricate nature of economic growth in relation to energy consumption, green technology adaptation, and the sustainability of environments in the emerging economies. Some of these nations have done well by incorporating renewable energy and clean technologies, yet their impact on their environment is still high, attributed to the forces of urbanization, industrialization and fossil fuel consumption. The relevance of formulating of policies, which facilitate the use of renewable energy resource, enhance energy efficiency and promote sustainable consumption patterns is brought out in the study. Moreover, it is important to amalgamate ecologically friendly technologies in the city-planning policy as the urban centers are the principal resource gravitators.

Decoupling of economic growth and environmental degradation is possible, but a lot of investment in green technologies, policy frameworks and infrastructure is needed. With the emerging economies still expanding, the need to implement these strategies will form part of their strategies towards achieving sustainability; however, they should be fashioned to suit their socio-economic situation. Some of the future research topics to be studied under the subject area should include the investigation of the performance of certain policies in an effort to minimize impact on ecological footprints and emission of carbon dioxide in various economies and the role that international collaboration plays in assisting in emerging economies to achieve sustainable growth.

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