An exploration of the relationship between Carbon Emission, PHDI and the Human Development Index

by

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Abstract

This paper employed data from 135 countries from the years 1990 and 2020 to explore the relationship between the HDI (Human Development Index) and CO_2 emission/per capita with the PHDI (Planet Adjusted HDI; an HDI measurement adjusted for CO_2 emission and material footprint/per capita. The secondary exploration of the paper involved determining whether there was an increase in the HDI over the span of the 3 decades (1990 - 2020). Pearson's correlation test, OLS regression model and a paired t-test were conducted for the purpose of this investigation. It was hypothesized that a positive relationship exists between the CO_2 emission/per capita and HDI when controlling for PHDI. This was confirmed with Pearson's correlation and OLS regression model which indicated that HDI increases with CO_2 emissions when PHDI acts as a control. Furthermore, results from the Paired t-test revealed that over the past 3 decades, the average HDI has increased.

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1. Introduction

1.1 Human Development Index

1.1.1 Dimensions

The Human Development Index was published by the United Nations Development Program (UNDP) in 1990. HDI considers the level of knowledge, the quality of health and the standard of living of a country and then calculates an index. While contributing factors such as mean years of schooling, life expectancy at birth and gross national income are directly used to define the dimensions of knowledge, health and standard of living, there are several factors that can be used to further refine what affects the HDI of a country (Roser, 2019).

1.1.2 Why HDI?

Prior to the HDI, the progress of a country was often measured directly by its economic progress. Financial development served as a testament to the nation's productivity. The UNDP created the HDI to put greater emphasis on the fact that the ultimate criteria for assessing the development of a country should be based on holistic factors and not economic growth alone (United Nations, 2022).

1.1.3 Looking beyond the existing dimensions

Zooming in on merely the above three dimensions once again narrows the scope of the indicator, which then starts to defeat its purpose of being a multifaceted measure of a country's growth. The life of the people in a nation is also dependent on material possessions, stable income, political stability, availability of utilities, levels of pollution, and the climate (Fontinelle, 2020). There is a complex relationship between these factors, among others, and it's important to explore the trends in sectors beyond the three primary dimensions of HDI. Therefore, the PHDI, and CO_2 emission/capita are chosen for the purpose of this exploration.

1.2 Research Question(s)

Primary Question: What is the relationship between CO_2 emission/capita and PHDI (planetary-adjusted HDI) on the HDI (human development index)?

Secondary Question: Has there been an increase in HDI over the three decades between 1990 and 2020?

1.3 Hypothesis

Since CO_2 emissions and PHDI are associated with higher economic activity and development in a nation, it was hypothesized that there will be a positive relationship between the independent variables (CO_2 emissions, PHDI) and the HDI. Furthermore, there has been significant strides made in various sectors like education, women empowerment over the past 3 decades which is why it was hypothesized that the HDI in 2020 will be greater than 1990.

2. Literature Review

Carbon Emissions, PHDI and the Economy

Growing efforts of developing and developed nations to actively reduce their carbon footprint is a strong sign of the need for citizens to be provided with cleaner, greener environments to thrive in. A global increase in temperature and drastic changes in the climate pose a threat to public health and to the economy. A study released in 2017 exposed that about 1 million air-pollution related deaths in the year 2010 were representative of close to 13% of the country's GDP. That same year, air pollution was the cause for over 22,000 deaths in the United Kingdom, representing up to 7% of the GDP (Sarao, 2020).

In addition to considering carbon emissions per capita, we're also looking at the PHDI; planetary pressure adjusted HDI. PHDI combines the data on carbon dioxide (CO_2) emissions per person (production-based) and material footprint per capita. CO_2 emissions per person (production-based) refer to the carbon emissions produced because of human activity such as using coal, oil and gas for combustion, cement manufacture, gas flaring, carbon emissions during industrial work, among others. Material footprint per capita is the sum of material footprints for biomass, fossil fuels, metal ores and non-metal ores. This index therefore helps put into perspective the human activity that is responsible for economic growth and shares the load of the carbon emissions produced in a country (Technical Note. Planetary Pressures-Adjusted Human Development Index (PHDI), n.d.).

It is crucial to understand the scope of studying HDI and particularly the factors that might influence HDI. For a country, it would certainly assist governing bodies to determine what sectors can benefit from improvement and implement specific policies to attain that. Successful implementation of such policies would allow residents of a nation to lead a purposeful life and make positive contribution to their society and economy. Moreover, the socio-economic status and performance of different countries can be tracked and improved based on the study of factors impacting HDI. In a nutshell, analyzing the HDI greatly influences change. Revising national policies, shifting budget priorities, amending current practices or laws, and thus, leading to promotion of gender equality, women empowerment, sustainability, education for all and global partnerships are just some of the specific ways in which the HDI can improved.

3. Method

3.1 Dataset

The dataset used for the statistical analysis is the Human Development World Index (HDI) of 135 countries retrieved from Kaggle data repository. HDI is a measure often used to rank countries into different tiers based on the country's living standard, their knowledge index and life expectancy. The calculation of the Human Development Index involves measuring the geometric means of the normalized indexes of the three above-mentioned dimensions.

This dataset consists of annual global data of HDI well as the key dimensions associated with HDI for each country from 1990 to 2020. Each column/dimension of the dataset represents a specific factor that the HDI takes into consideration. For example:

1. The standard of living of the individuals of the country can be addressed by referring to the Gross National Income Per Capita.
2. The knowledge index can be accessed by measuring the Mean Years of Schooling for Adults considering the age factor as 25 and above along with the Expected Years of Schooling for children.
3. The life expectancy data can be addressed by the Life Expectancy at Birth column of the dataset.

To capture a more comprehensive measurement of human development and determine the retreating groups in terms of development, other composite indices are found in the original dataset. These include the Planetary pressures-adjusted HDI (PHDI), Carbon Dioxide Emissions Per capita Production in Tones, Gender Social Norms Index (GSNI), Multidimensional Poverty Index (MPI), Inequality-adjusted Human Development Index (IHDI), Gender Inequality Index (GII), and Gender Development Index (GDI).

The dataset was filtered to contain information from the years 1990 and 2020 only. Out of the 50 columns present in the dataset, CO_2 Emission/capita (in Tons), PHDI, and the HDI were utilized as these were the variables of interest for the scope of this paper.

3.2 Measurement

1. Independent Variables

Carbon Dioxide Emissions Per capita Production in Tones: Increasing CO_2 emissions have impacted the environment, human health, and the economy, signifying a country's development. Therefore, CO_2 can be treated as a variable that may significantly affect the HDI.

Planetary Pressures Adjusted Human Development Index (PHDI): PHDI is an index that estimates the risk caused by continuing the current practices of global resource usage and the effect of environmental stress on development. This measure of human pressure on the planet is measured by taking into consideration factors CO_2 emissions and material footprint/capital

2. Dependent Variables

Human Development Index: HDI is a measure to track the development of countries while emphasizing factors associated with people and their capabilities, without exclusively focusing on a country's economic growth.

3.3 Data analysis

Several statistical methods were employed throughout this paper for the purpose of data analysis. Descriptive analysis performed provided a deeper insight into each of the variables and allowed for the organization of data in a purposeful manner. All statistical analysis was performed in R version 4.2.1. Pearson's Correlation Coefficient was calculated to analyze the strength and direction of the relationship between each of the variables as displayed in the correlation matrix. Ordinary Least Square (OLS) method of regression was also performed to investigate the simultaneous influence of independent variable CO_2 emission on the HDI, while controlling for PHDI. Furthermore, a paired T-test was performed to determine if there were any significant changes in the HDI between 1990 and 2020.

4. Results and Discussion

4.1 Descriptive results

Descriptive analysis was performed to get insight about the sample size, mean, and standard deviation split between three decades (1990 and 2020). From Table 1, it can be observed that the mean and standard deviation are not standardized, and the data distribution is not uniform. A sample size of 270 for all variables is also observed.

Table 1: Descriptive Statistics

Variables	Sample size (N)		Mean		Standard Deviation	
	1990	***2020***	***1990***	***2020***	***1990***	***2020***
CO2 Emission	270	270	4.90	4.44	6.50	5.55
Planetary Adjusted HDI	270	270	0.52	0.64	0.12	0.11
Human Development Index	270	270	0.59	0.72	0.17	0.16

Source: Human Development World Index from Kaggle.

To gain better insights, a scatter plot of matrices was created (Figure 1) to check the data distribution using histogram. This scatter plot of matrices also consists of information regarding the strength and the direction of linear correlation between all the variables. As seen in figure 1, Pearson's correlation for the human development index (HDI) and CO_2 emission is 0.56, indicating that there a moderate positive relationship between the dependent variable (HDI) and the independent variable (CO_2) exists. The Pearson's correlation coefficient for human development index and planetary Adjusted HDI is 0.88 which is very strong, suggesting that the PHDI, as a control variable, has a strong association with the dependent variable (HDI). However, there is a weak correlation of 0.18 between CO_2 emission and the PHDI.

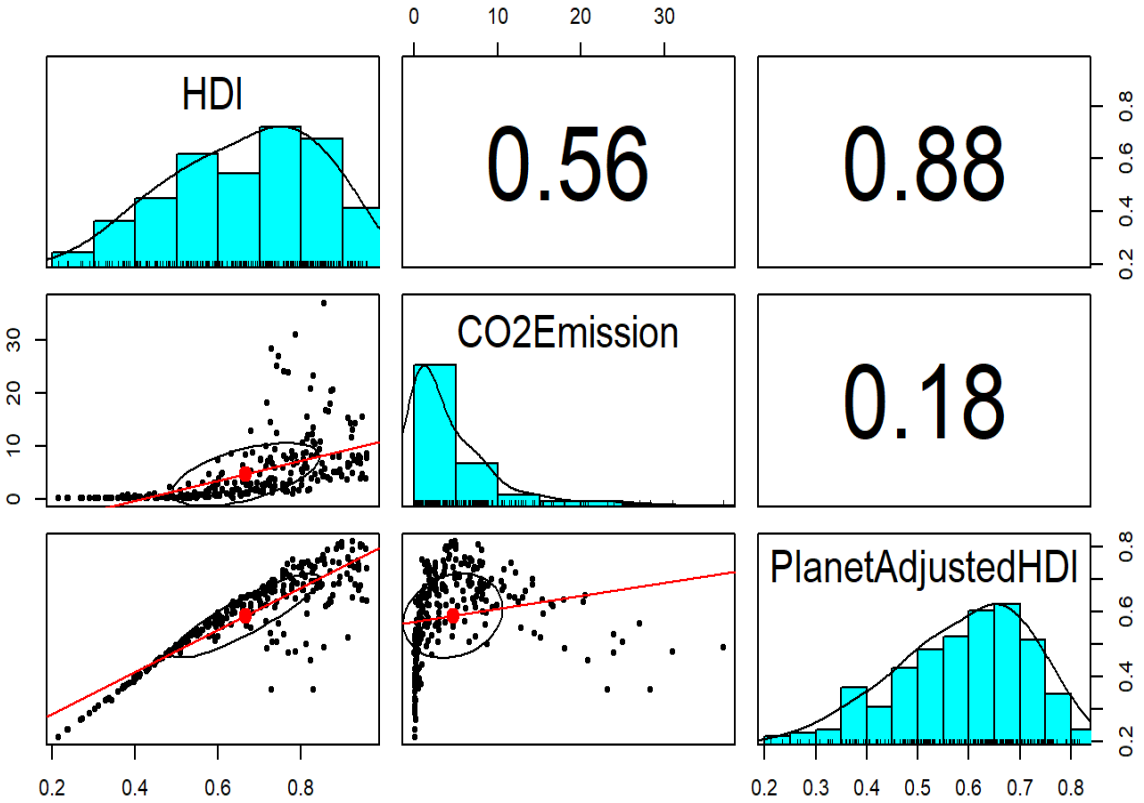

Figure 1: Scatter Plot of Matrices

4.2 OLS regression results

Ordinary Least Square model was used to predict the dependent variable, Human Development Index using CO2 emission and PHDI as the independent variables.

Table 2: OLS Regression Predicting Human Development Index

	b	**Significance**
Intercept	-0.0339794	0.00554 ***
CO2 Emission	0.0122391	< 2e-16 ***
Planetary Adjusted HDI	1.0957195	< 2e-16 ***
R-Squared	0.9411	
Sample size (N)	270	

Source: Human Development World Index from Kaggle.
Dependent Variable: Human Development Index (HDI)
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

From the result of the linear regression model, the following information can be obtained:

The R-squared value is 0.9411, which indicates that about 94.11% percent of the variation in the dependent variable (HDI in this research) can be explained by this linear regression model.

The intercept is -0.034, which means that when all variables take the value of 0, the human development index is -0.034. That is, the HDI is -0.034 when the CO2 emission and planetary adjusted human development index both have a value of 0. The intercept has a p value of 0.006 which is smaller than the significance level of 0.05, thus rendering it statistically significant.

The coefficient for CO_2 emission/capita in tones is 0.012 and has a p value of less than 2e-16, which means it is significantly different from 0. This suggests that a one unit increase in the CO_2 emission/capita is associated with a 0.012 unit increase in the HDI, holding other variables constant.

The coefficient for PHDI is 1.096 and has a p value of less than 2e-16, which means it is significantly different from 0. This suggests that one unit increase in the planetary pressures adjusted human development index is associated with 1.096 units increase in the human development index, holding other variables constant.

4.3 Paired t-test results

A paired t-test was conducted to determine if the mean of human development index [HDI] in 2020 is significantly greater than the mean of human development index [HDI] in 1990.

H_0 (Null hypothesis): mean (HDI (2020)) - mean (HDI (1990)) = 0

The mean value of human development index in 2020 does not differ to the mean value of human development index in 1990

H_1 (Alternative hypothesis): mean (HDI (2020)) - mean (HDI (1990)) > 0

The mean value of human development index in 2020 is greater than the mean value of human development index in 1990

Table 3: Paired T-Test

Mean Difference	SD_{pooled}	t	95% Confidence Interval of the differences		Significance
			Lower	Upper	
0.142	0.166	30.099	0.134	Inf	< 2.2e-16 ***

Source: Human Development World Index from Kaggle.

*** $p < 0.001$

With a p value of less than 2.2e-16 which is less than a significance level of 0.05, the null hypothesis can be rejected. It can be stated that the mean HDI in 2020 is indeed greater than the mean HDI in 1990.

5. Conclusion

The purpose of this study was to determine if there is a relationship between the HDI, CO_2 emission and PHDI. It was hypothesized that the HDI would increase slightly with an increase in the emission levels of CO_2 and PHDI signifying the ongoing development in the country which is associated with higher HDI values. Through the Ordinary Least Square analysis, this hypothesis was validated as it was evident that with an increase by one unit in the independent variable CO_2 emission and the control variable PHDI, the HDI will increase, and the results are statistically significant. The second component of this study was to investigate whether there was an increase in the HDI over the span of the three decades by comparing HDI values from 1990 to HDI values from 2020. The paired t-test was conducted, and it was concluded that the HDI has increased from 1990 to 2020 which can also be corroborated from the descriptive analysis where the difference between the mean values of HDI for these two years is noted.

6. References

Astika Saputra, F., Barakbah, A., & Riza Rokhmawati, P. (2020, September 1). Data Analytics of Human Development Index(HDI) with Features Descriptive and Predictive Mining. https://doi.org/10.1109/IES50839.2020.9231661

Costa, L., Rybski, D., & Kropp, J. P. (2011). A Human Development Framework for CO2 Reductions. PLoS ONE, 6(12), e29262. https://doi.org/10.1371/journal.pone.0029262

Fontinelle, A. (2020, July 21). Standard of Living vs. Quality of Life: What's the Difference? Retrieved from Investopedia website: https://www.investopedia.com/articles/financial-theory/08/standard-of-living-quality-of-life.asp

Indicators of Stages of Success in Economic Development. (2021, February 24). Retrieved from JURUSAN MANAJEMEN TERBAIK DI SUMUT website: https://manajemen.uma.ac.id/2021/02/indicators-of-stages-of-success-in-economic-development/

Mariano, E. B., Ferraz, D., & de Oliveira Gobbo, S. C. (2021). The Human Development Index with Multiple Data Envelopment Analysis Approaches: A Comparative Evaluation Using Social Network Analysis. Social Indicators Research, 157(2), 443–500. https://doi.org/10.1007/s11205-021-02660-4

Roser, M. (2019, November). Human Development Index (HDI). Retrieved from Our World in Data website: https://ourworldindata.org/human-development-index

Sarao, J. (2020, May 22). Reducing Carbon Emissions Will Benefit the Global Economy- Here's How. Retrieved from Earth.org website: https://earth.org/carbon-emissions-economy/

Technical note. Planetary pressures-adjusted Human Development Index (PHDI). (n.d.). Retrieved from https://hdr.undp.org/system/files/documents//phdi2020technicalnotespdf.pdf

United Nations. (2022). Human Development Index. Retrieved from United Nations Development Programme website: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

7. List of Appendices

```
## # A tibble: 2 × 11
##   Year  HDIMean HDISD CO2Mean CO2SD PAHDIM…¹ PAHDISD LFFMean LFFSD LFMMean LFMSD
##   <chr>   <dbl> <dbl>   <dbl> <dbl>    <dbl>   <dbl>   <dbl> <dbl>   <dbl> <dbl>
## 1 1990    0.590 0.174    4.90  6.50    0.520   0.124    47.9  18.3    77.1  7.57
## 2 2020    0.722 0.158    4.44  5.55    0.637   0.111    50.1  15.8    69.8  8.59
## # … with abbreviated variable name ¹PAHDIMean
```

Fig 1. Descriptive Table for dataset

```
##
## Call:
## lm(formula = HDI ~ CO2Emission + PlanetAdjustedHDI, data = HDI_90_20_combined_valid)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.167001 -0.017331 -0.008578  0.004887  0.193182
##
## Coefficients:
##                     Estimate Std. Error t value Pr(>|t|)
## (Intercept)       -0.0339794  0.0121505  -2.797  0.00554 **
## CO2Emission        0.0122391  0.0004486  27.283  < 2e-16 ***
## PlanetAdjustedHDI  1.0957195  0.0205512  53.317  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.04313 on 267 degrees of freedom
## Multiple R-squared:  0.9411, Adjusted R-squared:  0.9406
## F-statistic:  2133 on 2 and 267 DF,  p-value: < 2.2e-16
```

Fig 2. Linear Regression Summary

```
##
##  Paired t-test
##
## data:  HDI_90_20_valid$HDI.2020 and HDI_90_20_valid$HDI.1990
## t = 30.099, df = 114, p-value < 2.2e-16
## alternative hypothesis: true mean difference is greater than 0
## 95 percent confidence interval:
##  0.1342585       Inf
## sample estimates:
## mean difference
##        0.142087
```

Fig 3. Paired t-test result