The Impact of Renewable Energy versus Fossil Fuel Energy on Human Development

by

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Highlights

- Statistical analysis of renewable energy and fossil fuel energy contributions to development
- Models are created with the Human Development Index (HDI) to measure development beyond economic growth
- A negative linear correlation is found between fossil fuel energy consumption and HDI for LMI countries
- Renewable energy can promote access to energy and decarbonization in LMI countries without negatively affecting HDI

Abstract

As the effects of the climate crisis grow more severe annually, countries around the world have increased their commitments to increasing renewable energy consumption to mitigate greenhouse gas emissions. While renewable energy consumption greatly reduces emissions, it is wondered if renewable energy or fossil fuel energy consumption contribute differently to country development. This study aims to understand differences in relationships between fossil fuel energy consumption and development versus renewable energy consumption and development. The Human Development Index (HDI) framework is used as a proxy to represent country development to incorporate a more holistic approach to quantifying development instead of merely using gross domestic product (GDP). Using a sample of low-to-middle income (LMI) countries, methods include statistical regression analysis to understand these relationships. Results show that there is a negative, linear correlation relationship between fossil fuel energy consumption and HDI. There is not enough evidence to suggest a regression relationship, linear or otherwise, between renewable energy consumption and HDI. The results add to the growing body of research that shows that the benefits from fossil fuels do not outperform renewable energy. Countries will continue to increase consumption of renewable energy for global decarbonization and to increase access to energy.

Key Words

Sustainable development; Low-to-middle income (LMI) countries; Energy consumption; Human development; Renewable energy

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1. Introduction

Literature shows that energy consumption is directly related to increasing development. In the face of the climate crisis, nations are moving towards decarbonized energy sectors to shift towards a global zero-carbon society. Since populations within low-to-middle income (LMI) nations are projected to grow and industrialize the greatest amount in the next decade by 2030, it is important to explore non-fossil fuel options that will support these populations and economies to transition to clean, low-carbon societies. It has been noted that renewable energy is integral in the global fight against climate change to decarbonize the energy sector (Singh et al., 2019). However, it is important to understand if there are tradeoffs for forgoing fossil fuels that will affect country development, especially when considering LMI countries.

This paper seeks to address the question: does consuming renewable energy impact country development differently than fossil fuel energy consumption for LMI countries? The statistical regression analysis uses data from 36 LMI countries in 2019 for fossil fuel energy consumption, renewable energy consumption, and Human Development Index (HDI) index scores. Additionally, the HDI scores (2019), Energy Development Index ratings (2019), and Energy Trilemma Index ratings (2019) are used to discuss and frame the analysis.

It is widely assumed that energy consumption and economic growth are highly correlated and have a linear, positive relationship (Arto et al., 2016; Azam et al., 2021; Bhattacharya et al., 2016; Singh et al. 2019). Energy is a crucial tool needed for cultural, social, and especially economic development of countries (Arto et al., 2016; Sovacool, 2012; Tully, 2008). This assumption is rooted in the literature reviewed and its evidence on the transformational effects of energy on community, national, and societal levels. It is then questioned, what is the relationship between renewable energy and development at the national level? Moreover, does this relationship correlate differently to the relationship between fossil fuel energy and development at the national level?

2. Background

2.1 Access to Electricity and Energy

Access to energy is a basic human right, where literature has gone further to proclaim access to clean energy sources as a human right (Tully, 2008). Moreover, the 1986 UN General Assembly shared the Declaration Right to Development, which states that since development is a human right, countries have a right to develop (United Nations General Assembly, 1986). Access to energy is a driver for wellbeing and one of the main ways to improve quality of life (Castro-Sitiriche & Ndoye, 2013). Sustainable development is intrinsically tied to energy justice by providing access to energy while also not polluting the earth (Guruswamy, 2010; Ilskog & Kjellström, 2008; Tully, 2008).

As of 2019, approximately 840 million people globally did not have access to electricity (IRENA, 2019). Specifically, Lestari et al. states that 14% of the global population is without access to electricity (2018). Energy deprivation is intrinsically tied to poverty, and costs related to energy for households in LMI countries can account for a majority portion of income (Sovacool, 2012). Increasing energy access opens avenues to reduce poverty in LMI countries since roughly 84% of LMI countries' communities live in rural areas (Lestari et al., 2014). Rural communities have untapped renewable energy sources to provide clean energy access to communities while also not degrading the earth and its environment (Doukas et al., 2012). Helping rural communities gain access to electricity while also not contributing to climate change or environmental (water, air, land) pollution through the burning of fossil fuels is an important aspect to providing access to energy as a human right.

In particular, West African nations have potential for renewable sources other than biomass such as wind, solar, and hydro (Maji et al., 2019). There is the potential to develop with renewable energy consumption without relying on fossil fuels, which will provide access to energy and also reduce pollution in these countries. However, it is important to understand if transitioning from fossil fuel consumption negatively impacts development to LMI countries as these communities have contributed the least to the global climate crisis.

2.2 The Rise of Renewable Energy

A subset of literature highlights the benefits and drawbacks of implementing renewable energy in a community at differing capacities. The literature shows access, equity, environmental, and economic benefits are associated with renewable energy implementation. One such benefit is that renewable energy creates a greater number of jobs than fossil fuels (Llera Sastresa, 2010). Prior research also states that renewable energy implementations lead to reduced greenhouse gas emissions into the atmosphere and development of communities leading to increased living standards. It is estimated that as of 2018, renewable energy accounted for approximately 26.4% of electricity use globally (excluding heating, cooling, and transport), and accounted for 11% of total final energy consumption, which excludes traditional biomass use (REN21, 2020). In the future, renewables generation capacity is forecasted to grow upwards of 50% between 2019 and 2024 due to increased global demand and decreased capital costs (IEA, 2019). Renewable energy is necessary for sustainability, economic growth, and welfare (Azam et al., 2021).

A subsection of the literature identifies the urgent need to adopt renewable energy as a larger portion of electricity production and consumption globally due to increased climate change effects and the negative consequences of burning fossil fuels, which includes increased air pollution and less resource security (Sadorsky, 2009). Renewables have social benefits as well, for example, renewable energy in the local communities can increase security by providing lighting at night (Setiawan & Setiawan, 2013). In India, renewable energy is consumed for the purposes of lighting, cooking, business applications and applications for the advancement of new sustainable technologies, which is significant considering India is currently in the top five highest emitters of greenhouse gas emissions and per capita power consumption is increasing annually (Ahmad & Alam, 2018).

Contrastingly, Cebotari & Benedek found that renewable energy capacity additions have no significant impact on economic indicators such as employment or increased local revenue when reviewing community-specific renewable energy projects in certain regions of Romania (2017).

2.3 Energy and Development

The concept of country development is presented and analyzed in different contexts from the technical, economic, sustainability, and social factors. The term "development" can be defined to go beyond economic development to encompass other facets of country progress (Bhattacharyya, 2012). In fact, development has been equated to prosperity in literature to include social factors, ecological sustainability, and quality of life to be more comprehensive than merely economic development (Fritz & Koch, 2016). Arto et al. state that energy and development are connected and to analyze development, one must look at consumption rather than total primary energy due to factors such as globalization and the flow of goods and services (2016). For LMI countries (classified as HDI ≤ 0.8), the relationship between energy consumption and increased development is strongly correlated at low levels of energy usage, whereas for developed countries (classified as HDI ≥ 0.8), the relationship plateaus due to these countries minimizing energy intensity and maximizing energy efficiency measures (Arto et al., 2016).

Steinberger found that for 2012 the relationship between HDI and energy use per capita for a 137-country sample to be highly, positively correlated at small values of energy consumption for capita (2016). Though as energy consumption per capita increases, the relationship stagnates at an HDI value of approximately 0.8 based on the principle of diminishing returns (ibid). It is noted that this study was conducted on total energy consumption per capita and does not delineate between fossil fuel energy consumption and renewable energy consumption.

Azam et al. found in their recent study that both fossil fuel consumption and renewable energy consumption have a positive and statistically significant long-run impact on economic growth (2021). Contrastingly, Maji et al. found that renewable energy consumption reduces economic growth for a study on 15 countries in West Africa form 1995-2014 (2019). One study concluded that of the top 38 renewable energy consuming countries globally, a majority (57%) of those countries had renewable energy as a significant driver of economic growth (Bhattacharya et al., 2016). When looking at more factors (ecological sustainability, social inclusion, individual wellbeing, and quality of life) than merely GDP as a proxy for economic growth, Fritz and Koch found that as economic development increases for countries, social prosperity indicators increased while sustainability indicators decreased (2016). The literature shows that while renewable energy may not be a significant driver for specifically economic growth of LMI countries, there is not significant research on the relationship between renewable energy consumption and development beyond economic growth.

2.4 Indicator Frameworks Discussed

The literature presented indicator frameworks to measure development as more holistic than merely economic growth. The different indicators of sustainable development that embodied the triple bottom line of sustainability: people, planet, and profit. The indicator frameworks represent the numerical representation of synthesized data and analysis to make information more understandable to a wider audience (Ilskog & Kjellström, 2008). These indicators varied, but commonly included categories of technical, economic, social/ethical, environmental, and institutional factors. These indicator frameworks illustrate different ways to measure either energy development or country development that go beyond measuring economic growth. Using information that goes beyond economic development, these frameworks can give a more holistic view on the topics of energy and development. Table 1 shows a list of indicator systems present in the reviewed literature (see Table 1). Some of the common indicators sets utilized in analysis presented in the literature included human wellbeing indicators such as the HDI and Happy Life Years (HLY); energy indicators such as the Energy Trilemma Index (ETI) and the Energy

Development Index (EDI); and social/prosperity indicators such as the Social Impact Method of Energy Analysis (SIMEA) (see Table 1).

Table 1. Summarized Indicator Frameworks Incorporating Energy and/or Development

Framework	Indicators (factors) Considered
Helio International's Sustainable Energy Watch (SEW) indicators	1. Global impacts: energy sector carbon emissions per capita (environmental) 2. Local impacts: level of most significant local energy pollutant (environmental) 3. Households with access to electricity: share of households with access (social) 4. Investment in clean energy, as a proxy for job creation: renewable energy and energy efficiency investment as share of total energy sector investment (social) 5. Resilience to external trade impacts, Non-renewable energy (NRE) exports as a share of total export value, NRE imports as a share of total primary energy supply (economic) 6. Burden of energy investments on the public sector: public investment in NRE sector as share of GDP (economic) 7. Energy intensity: primary energy consumption per unit of GDP (technological) 8. Use of renewable energy: renewable energy supply as a share of total primary energy supply (technological)
Sustainable Development Indicators (SDI)	1. Socioeconomic development 2. Sustainable consumption and production 3. Social inclusion 4. Demographic changes 5. Public health 6. Climate change and energy 7. Sustainable transport 8. Natural resources 9. Global partnership 10. Good governance
Human wellbeing indicators	1. Life expectancy (at birth) 2. Subjective wellbeing measures (Cantril Ladder and Overall life satisfaction) 3. Happy life years (HLY): combination of life expectancy and normalized value of life satisfaction 4. Ecological footprint 5. Human development index (HDI): a long and healthy life, knowledge, and decent standard of living 6. Happy planet index: ecological efficiency with which happy and healthy lives are supported 7. Per capita electric energy consumption 8. Per capita CO2 emissions 9. Energy Intensity
Energy Sustainability Index (ESI)	1. Population density 2. Energy consumption per capita 3. GDP per capita 4. Renewable energy sources (RES) production per capita 5. Fossil fuel consumption per capita 6. % RES electricity

	7. % RES thermal 8. RES per fossil fuel electricity production 9. % Ratio of local residents to peak season tourists
Energy Development Index (EDI)	1. Access to clean cooking facilities 2. Access to electricity 3. Access to energy for public services 4. Access to energy for productive use
Social Impact Method of Energy Analysis (SIMEA)	1. Economic 2. Technological 3. Environmental 4. Social
Prosperity Indicators	1. CO2 emissions in tons/capita (ecological sustainability) 2. Ecological footprint of production in global ha per capita (ecological sustainability) 3. Ecological footprint of consumption in global ha per capita (ecological sustainability) 4. Gini index for income inequality (social inclusion) 5. Homicide rates per 100,000 persons (social inclusion) 6. Democracy index (social inclusion) 7. Freedom house index (social inclusion) 8. Life expectancy (quality of Life) 9. Literacy rates (quality of Life) 10. Subjective wellbeing (quality of Life)
Happy Life Years (HLY)	1. Combination of life expectancy and the normalized value of life satisfaction to obtain an approximate value of expected years lived satisfied
Human Development Index (HDI)	1. Life expectancy 2. Expected years of schooling 3. Mean years of schooling 4. Gross National Income (GNI) per capita
Energy Trilemma Index (ETI)	1. Energy equity 2. Energy security 3. Environmental sustainability of energy systems 4. Country context

The Human Development Index (HDI) is used both as the response variable in the statistical analysis for selected countries from 2019 and in the discussion of comparison of indicator frameworks. The factors that are used to create the HDI indicator include 1) long and healthy life, 2) knowledge, and 3) a decent standard of living (United Nations Development Programme, n.d.). Factors are incorporated in the model using the following normalized proxy variables: 1) life expectancy at birth, 2) expected years of schooling and mean years of schooling, and 3) GNI (Gross National Income) per capita are used to quantify the factors of the HDI (see Table 1 above). To calculate the HDI, the three factors are normalized, and the geometric mean is taken (United Nations Development Programme, n.d.). The HDI is a simple and well-known tool to measure development using country data to give an overview of human development of countries. Despite its simplicity, the HDI falls short in comprehensiveness as it does not account for inequalities within countries, such as disparities in income (Bhattacharyya, 2012). Another drawback of the HDI is that it fails to incorporate factors for social and environmental wellbeing for countries (Castro & Ndoye, 2013).

3. Methods

3.1 Data

Data is used from a sample of 36 LMI countries globally for the year 2019 (see Table 2) and is aggregated for the statistical analysis from the United Nations Development Programme's Human Development Reports (2020) and the British Petroleum Statistical Review (2019). Methods include a statistical regression analysis of the relationship between HDI and fossil fuel consumption versus HDI and renewable energy consumption for the year 2019.

Table 2. LMI countries included in the data sample (n = 36)

World Region	Countries Included in Sample
Africa	Algeria, Egypt, Morocco, South Africa
Americas	Argentina, Brazil, Chile, Colombia, Mexico, Peru, Venezuela
Asia Pacific	Bangladesh, China, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, Vietnam
Europe	Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Russia Federation, Slovak Republic, Slovenia, Turkey, Ukraine
Middle East	Iran, Kazakhstan

In 2019 according to the World Bank, these 36 LMI countries represented in total ~64% of the world's population and ~36% of the world's gross domestic product (GDP) in current U.S. dollars (2019). Additionally, the 36 LMI countries have an average of 5.0 metric tons per capita of CO_2 emissions in 2016, which was the last year country data was collected on this metric (ibid). Additionally, as projected by the IEA it is estimated that China, India, and Russia Federation will be in the top 5 greenhouse gas emitting countries by 2030, accounting for approximately 59% of world emissions (Sadorsky, 2009).

3.2 Statistical Analysis

Using data detailed above from the 36 countries for the year 2019, the variables of renewable energy consumption, fossil fuel consumption, and HDI are used in the quantitative analysis to create two models. In the statistical model, the variables, their descriptions and their data source are illustrated below (see Table 3 below).

Table 3. Variables used in the statistical model including REC, FFC, and HDI

	Variable	Description	Source
REC	Renewable energy consumption	Renewable energy consumption for countries based on wind, solar, geothermal, biomass/biofuels, and hydroelectric. Measured in exajoules (EJ).	BP Statistical Review of World Energy
FFC	Fossil fuel consumption	Fossil fuel energy consumption for countries based on coal, oil, and natural gas. Measured in exajoules (EJ).	BP Statistical Review of World Energy
HDI	Human Development Index	HDI ratings for countries from 2010 to 2019 measured on a scale from 0 (no/little human development) to 1 (strong human development).	UNDP Human Development Index (HDI) Rating

The two model functions are given below in equations 1 and 2 (respectively, model 1 and model 2), where Y is the HDI of the countries, REC is the renewable energy consumption of the countries, and FFC is the fossil fuel consumption of the countries (see Equations 1 and 2). The natural logarithmic transformation is used for both explanatory variables to meet the linearity assumption for linear regression. The histograms of the three variables of HDI, the natural logarithmic transformation of REC, and the natural logarithmic transformation of FFC are normally distributed with approximately normal skewness.

(Equation 1) $Y = f\{\log_e(REC)\}$

(Equation 2) $Y = f\{\log_e(FFC)\}$

Regression techniques, specifically linear regression, are used because they are straightforward, simple, and digestible to a large audience of people (Shalizi, 2017). Simple linear regression is chosen for both models (see Equations 1 and 2) based on our background knowledge of the highly correlated relationship between energy consumption (both fossil fuel and renewable) and development. This study breaks down energy consumption into the two different models due to the fact that the two explanatory variables of fossil fuel consumption and renewable energy consumption are highly correlated (see Results below).

A major assumption for this statistical analysis is the use of the 95% confidence intervals, which translate to a significance level (alpha) of 0.05. For the data, outliers and influential points are investigated after the variable transformations. To test for outliers, the classical Bonferroni correction (significance level = alpha / n) is used since there is no prior information available on outliers. Using boxplot visualization and Grubbs test for outliers and Cooks Distance test for influential points, the outputs indicated that there are neither outliers nor influential points.

For model 1, simple linear regression is used to assess FFC as the explanatory variable and HDI as the response variable. Simple linear regression relies on Ordinary Least Squares (OLS) method of regression, which works to have estimators of variables minimize the variation in errors for a given model. The residuals of model 1 upheld the assumptions to use linear regression, namely normality and homoscedasticity. The simple linear regression model for HDI versus fossil fuel consumption is shown below (see Equation 3).

(Equations 3 and 4) $f(x) = \beta_0 + \beta_1 x_i + \xi,$ where x_i = FFC or REC

For determining the beta parameter estimate (slope), hypothesis testing is used for t-test statistics. The null hypothesis is that the estimate of the parameter is not a significant predictor for the model while the alternative hypothesis is that the estimator is a significant predictor for the model. For linear regression, it is important to reject the null hypothesis at the set significance level so that the parameter estimate can create the slope of the linear model.

In addition to regression, bootstrapping was used to estimate the values of the regression output for parameter estimates and adjusted R-squared values. Bootstrapping can be used to show the approximate sampling distribution through case resampling at B number of repetitions. For this analysis of bootstrapping, we use B = 1,000 for the number of samples. It is also noted that case resampling is a bootstrapping technique that can be used for non-parametric (distribution agnostic) models. This is helpful when the model's true distribution is unknown. Case resampling is a conservative method of bootstrapping. With the bootstrapping of the parameter estimates and the adjusted R-squared values, histograms and confidence intervals are constructed to see the outcome of the sampling distribution due to this process.

For model 2, regression is used to assess REC as the explanatory variable and HDI as the response variable. When testing the assumptions for simple linear regression as outlined above, model 2 did not meet the requirement for constant variance of the residuals despite the logarithmic transformation used on the explanatory variable. Other transformations were explored yet proved unsuccessful to correct the variance of the residuals. Therefore, the GLS (Generalized Least Squares) method was used, which is a linear regression method to estimate parameters that does not require constant variance of the residuals (i.e., is heteroskedastic) (see Equation 4 above). The GLS method found no significance of the estimate of the explanatory variable (REC) at a p-value of 0.163. Since it was determined that there is no linear relationship between REC and HDI, splines are used to determine if there is a non-linear relationship between the two parameters. Since there are only 36 observations in the sample, it has been examined in previous studies to have approximately 10 to 15 observations per each term in the regression model (total number of terms = independent variables + interactions + polynomial terms) to accurately model the curve (Babyak, 2004). With this information, it was determined to use 3 knots (df = 3) for a cubic spline with B-splines being the method used.

Finally, to explore the strength of both models 1 and 2, the standard statistical values of the adjusted R-squared and Mean Squared Error (MSE) are assessed.

4. Results

The summary statistics of the 2019 data for the 36 countries used in the statistical model can be seen below (see Table 4). Interestingly, the correlation coefficient between the two models' explanatory variables (REC and FFC) is ~0.95 by Pearson's pairwise correlation test, showing that the two variables are highly correlated since the value is greater than 0.8 (Asongu et al., 2017).

Table 4. Summary statistics of the data

	HDI	REC	FFC
Minimum	0.56	0.01	0.13
1st Quartile	0.72	0.07	0.87
Median	0.78	0.25	2.54
Mean	0.78	1.04	7.55
3rd Quartile	0.85	0.50	5.18
Maximum	0.92	17.95	120.64

4.1 Model 1 Results

For model 1, linear regression was sufficient to model the relationship between HDI and fossil fuel consumption for the sample (see Figure 1).

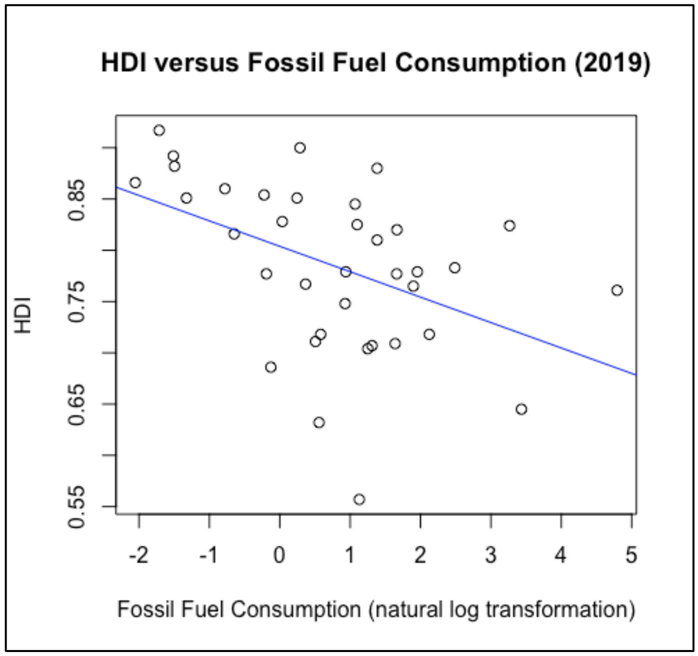


Figure 1. Plot of HDI versus fossil fuel consumption (n = 36)

The output values from model 1 can be seen in table 5 (see Table 5). The beta parameter estimate value (slope) is -0.025 with a t-test statistic value of -2.94 and a p-value of 0.0059. Through our hypothesis testing and at a significance level (alpha) of 0.05, we reject the null hypothesis, and it can be concluded that fossil fuel consumption is a significant linear predictor for HDI. From the parameter estimate, the 95% confidence interval is (-0.042, -0.0077). The adjusted R-squared value from the model output is 0.18 (or 18%). From the bootstrapping, the beta parameter estimate is approximately -0.025 with a 95% confidence interval of (-0.039, -0.01). The bootstrapped adjusted R-squared value is 0.18 (or 18%) with a 95% confidence interval of (0.01, 0.42). For the MSE, the value is 0.0053, which is the same value output for the bootstrapped MSE.

Table 5. Model 1 (HDI ~ FFC) outputs

	Parameter Estimate	**Parameter Estimate Confidence Interval**	**t-test statistic**	**p-value**	**Adjusted R^2**	**Adjusted R^2 Confidence Interval**	**MSE**
Original OLS Model	-0.025	(-0.042, -0.0077)	-2.94	0.0059	0.18		0.0053
Bootstrap Model	-0.025	(-0.039, -0.01).			0.18	0.01, 0.42)	0.0053

4.2 Model 2 Results

For model 2, the assumptions for linear regression were not met since the variance of the residuals were not constant. Through using GLS method, the beta parameter estimate had a value of -0.012 with a t-test statistic value of -1.23 and a p-value of 0.163. The 95% confidence interval for the parameter estimate is (-0.028, 0.0044). The p-value is greater than our significance level threshold and the confidence interval includes the value of 0. Therefore, in our hypothesis testing, we fail to reject the null hypothesis and conclude that renewable energy consumption is not a significant linear explanatory variable for HDI. The MSE of the GLS model is 2.23.

Table 6. Model 2 (HDI ~ REC) outputs

	Parameter Estimate	Parameter Estimate Confidence Interval	t-test statistic	p-value	Adjusted R^2	Adjusted R^2 Confidence Interval	MSE
Original GLS Model	-0.012	(-0.028, 0.0044)	-1.23	0.16			2.23
Spline Model	$X = 0.27$; $X^2 = -0.19$; $X^3 = 0.051$		$X = 1.71$; $X^2 = 1.79$; $X^3 = 0.51$	$X = 0.097$ $X^2 = 0.083$; $X^3 = 0.61$	0.080		0.0056

Since a linear model is no longer viable, the spline model with 3 degrees of freedom is evaluated (see Figure 2). The model output gives the beta parameter estimates for x to be equal to 0.27 with a p-value of 0.0972 (t = 1.71), for x^2 equal to -0.19 with a p-value of 0.083 (t = -1.79), and for x^3 equal to 0.051 with a p-value of 0.61 (t = 0.51). Based on the results, it is concluded that a cubic spline regression does not accurately show the relationship between renewable energy consumption and HDI. The adjusted R-squared value is 0.080 (or 8%). The MSE for the spline regression model is 0.0056. The output values from this model can be seen in table 6 (see Table 6). Since both linear regression and spline regression analysis was conducted and no relationship between renewable energy consumption and HDI was found, this analysis concludes that there is not enough evidence to suggest a relationship between these two variables.

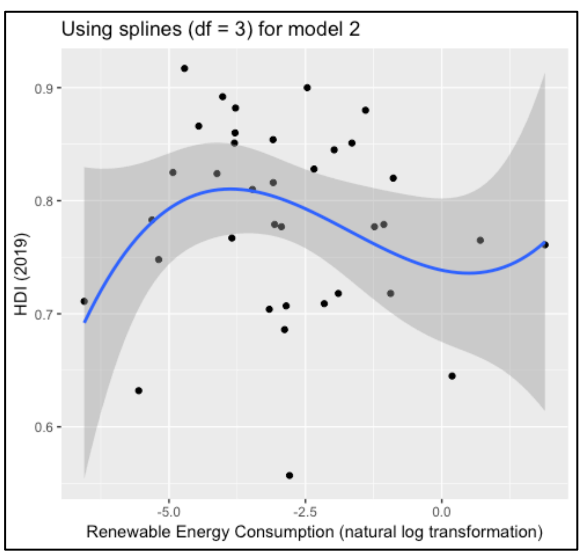


Figure 2. Regression model using splines HDI versus renewable energy consumption (df =3)

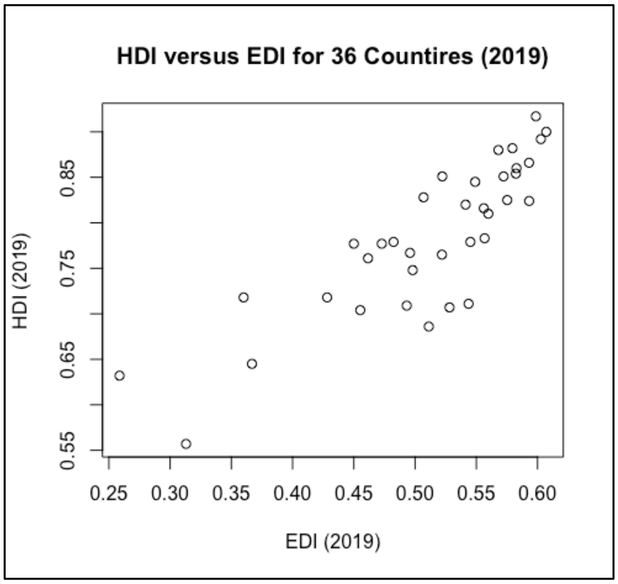
5. Discussion

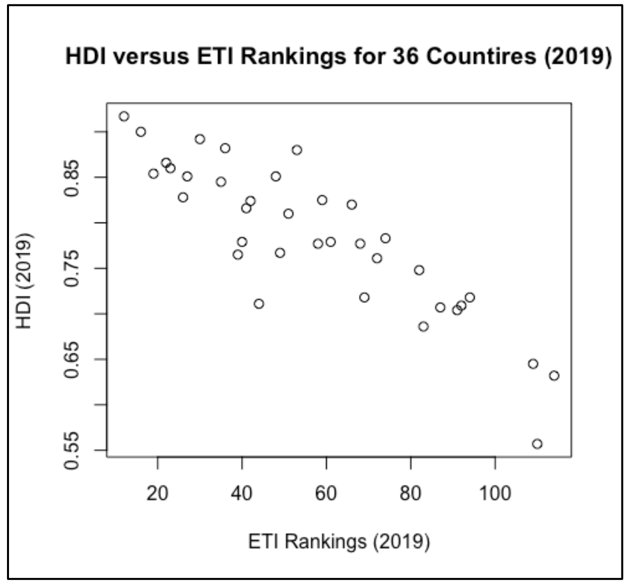
From this research, we found that renewable energy does not have a direct relationship with HDI, yet from the literature reviewed it is known that development is dependent on overall energy consumption. The type of relationship varies when measuring development as solely economic growth or as measured by the HDI. However, this study demonstrated that there is a negative correlation between fossil fuel consumption and HDI, which this study used to measure country development. This negative relationship between fossil fuel consumption and HDI could be due to a number of factors in LMI countries such as political instability, struggling healthcare systems, or other explanations. The adoption of increased renewables in the future by LMI countries may be driven by the push for decarbonization and access to energy, rather than specifically to further human development. From the literature, we know that access to energy overall increases development and also access to renewable energy decreases greenhouse gas emissions.

Increasing development does not have to conflict with decarbonization for countries as renewables provide access to energy and contribute to decarbonization efforts of countries. Therefore, increasing renewable energy consumption may have a significant impact on HDI or other developmental indicators for LMI countries with more data or using another year to study. This could be due to fact that the share of renewables in energy consumption for LMI countries is increasing annually (IEA, 2019).

In figures 3 and 4 below, the general trends are shown for the HDI, EDI, and ETI rankings of the 36 countries in the sample (see Figures 3 and 4). As shown in Table 1, the HDI measures human development of countries, the EDI measures access to energy and energy consumption to evaluate energy development, and the ETI measures energy sustainability, equity, and security for countries. The ETI weighs renewables more favorably than fossil fuels when ranking countries in terms of environmental sustainability of energy systems. For context, a ranking of 1 is the strongest ETI ranking, while a ranking of 128 is the weakest ETI ranking.

For the plot of HDI versus EDI, there is an approximately positive correlation between the two frameworks, which shows when the EDI (energy access) increases for the LMI countries in the sample then HDI (human development) increases also (see Figure 3). Contrastingly, for the ETI rankings of the LMI-sampled countries, there is a negative relationship for the plot between ETI rankings versus HDI (see Figure 4). This shows that as the ETI rankings of LMI countries in the sample increase (worsen), then HDI decrease. The trend shown in figure 4 below supports the research in this study, which illustrates that as fossil fuel consumption increases and therefore ETI rankings increase, then the human development of the sample countries decreases. A potential reason for this negative correlation between ETI and HDI is due to externalities associated with fossil fuel consumption, such as negative human health impacts and environmental pollution. Additionally, these trends could pose implications for how access to sustainable energy affects human development and access to energy in these LMI countries.





Figures 3 – 4. Indicator frameworks graphed against each other. (in order) HDI versus EDI Framework and HDI versus ETI Rankings for n = 36 sample

Regression models are an integral tool to understand the overall relationship and trends between explanatory and response variables. The EDI and the ETI are both plotted against the HDI for the LMI countries in the data sample in figures 3 and 4 above to show trends between human development versus energy development and also human development versus the ETI, which measures energy sustainability, equity, and security. Since the results for model 2 show no significant relationship between renewable energy consumption and HDI, the additional indicator frameworks provide alternative tools to dive deeper into how energy, and especially energy sustainability, plays a role in the LMI countries included in the study sample. For example, out of the 36 countries sampled, China in 2019 had the greatest fossil fuel energy consumption (120.6 EJ) and greatest renewable energy consumption (17.9 EJ) yet compared to other countries in the sample fell in the bottom 50% for the HDI values (HDI = 0.761). A large portion of China's renewable energy consumption can be attributed to hydroelectricity, which accounts for roughly 63% of renewable energy consumption in the country. China is the world's largest producer of hydroelectricity and includes projects such as the Three Gorges Dam (IHA, 2019; USGS, n.d.). Contrastingly, Latvia consumed the least amount of fossil fuels in the sample for 2019 (0.13 EJ) yet landed in the top 50% for the HDI rating (HDI = 0.866) of the 36 countries. Latvia's case shows that fossil fuel consumption is not a direct link to having strong country development. Using the HDI, EDI, and ETI contextualizes the larger picture of what energy and development look like in the 36 LMI countries for the year 2019.

While this research provides insights into the relationship of fossil fuel energy consumption and its relationship to HDI for the sample of countries, there are limitations to the study. First, the number of observations in the study was small compared to the number of LMI countries globally (~165 countries). The amount of available data limited the sample size, and more data could have strengthened the models for both HDI versus fossil fuel consumption and HDI versus renewable energy consumption. The small sample size could be an indication as to why there is no significant relationship between renewable energy consumption and HDI.

Additionally, limitations to the HDI as a developmental indicator includes using national averages for quantifying the values to calculate the aggregate HDI, which countries can contain variation within these values that is not reported (Bhattacharyya, 2012). Arto et al. states that country energy consumption may not be an accurate representation of energy usage in a country because of energy imports from other countries (2016). In the same paper, another limitation is the absence of global energy datasets for the computation of imports and exports of energy on a country-level bases (ibid).

Finally, the MSE values for both model 1 and the spline output for model 2 were small (close to 0). This could be due to the small range for the HDI values (y-values in model 1 and model 2) from 0 to 1. Further analysis could investigate the regression models using the cumulative distribution functions of the logistic or standard normal distributions. The outcomes of using these alternative methods could be compared to the original model analysis results. Finally, further analysis could investigate if there is a causal relationship beyond correlations between HDI and fossil fuel energy consumption.

6. Conclusion

This study aims to understand the different relationships between fossil fuel energy consumption and HDI separately from renewable energy consumption and HDI. The Human Development Index is used to measure development beyond economic growth and incorporate other country growth factors. The statistical analysis used a sample of 36 LMI countries to examine regression models and strength of models. Results show that there is a negative, linear relationship between HDI and fossil fuel consumption, while there is not enough evidence to suggest a relationship between HDI and renewable energy consumption.

The study shows that when comparing fossil fuel energy versus renewable energy, fossil fuel consumption may not lead to positive development outcomes for LMI countries, especially when using holistic development indicators that incorporate more than economic factors (such as GDP growth). Though no significant regression relationship could be determined between HDI and renewable energy consumption, this does not negate the fact that renewable energy consumption is increasing and will continue to increase in the future (Bhattacharyya et al., 2016). While renewable energy consumption cannot be explicitly linked to positive developmental outcomes for LMI countries from this study, renewable energy consumption is still vital since increased consumption will contribute to increased energy access and also energy decarbonization. Renewables also importantly supplement or replace fossil fuel energy to decrease greenhouse gas emissions. Renewable energy can provide clean, resilient, and affordable options for providing electricity and energy for country populations. Further, this study demonstrates that developing with fossil fuels is not beneficial for the climate, nor for the wellbeing of nations as measured by the HDI.

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