Predictions for Investments in Renewable Energy Infrastructure in African Nations

Pink, Thomas
Institute for Computational and Data Enabled Science and Engineering

Department of Industrial Engineering

tjpink@buffalo.edu

Abstract— **Most of the population growth occurring today is happening in developing countries. As their population rises, so will their demand for energy. As these countries develop new infrastructure for energy production, it is imperative that they build as much renewable energy infrastructure as possible. Many of the populations in African countries are rising quickly, this rise in population will require new cities to be built, requiring new energy demands. Many countries in Africa are having difficulty raising funds to pay for building the infrastructure for these renewable technologies, as most of this funding comes from investors in the first world. This paper seeks to use predictors such as urban population, GDP, political stability, and solar generation with the response variable of yearly investments in successful renewable energy projects. After creating models using a linear model, random forests, bagging, and BART, it was determined that urban population and political stability are the most important predictors in successful investments.**

I. Introduction

Africa is seeing a large growth in urban population in recent decades, that is only projected to increase in upcoming decades. This growing urban population is going to have growing energy demands, which should be met with renewable energy sources. Since most funding for renewable energy infrastructure in African countries is from investors in first world countries, it is imperative that these investors have data driven confidence in their investments. The investments made can be risky due to the instability of many African nations, and minimizing the risk of these investments will likely lead to more, and larger, investments in the future. This paper includes literature reviews on relevant work to determine which predictors are most important for the analysis. The predictors are visualized, showing initial correlations in the data. The models are described and are run on training data. The results and accuracy of these models are shown and discussed, leading to conclusions and discussions on future research.

II. Literature Review

This literature review seeks to analyze the current understanding of renewable power generation in Africa. Literature has been reviewed from a wide variety of topics. This includes the economic feasibility of renewable energy in Africa, political and social influences which can impact developing renewable energy, and analysis of the concerns among stakeholders in renewable energy infrastructure. This review provides a background for the importance and scope of this project. This review helped determine which important predictors were chosen in the data collection of this project.

The first important topic of discussion is whether there is a correlation between growth in renewable energy technology and economic growth. There is no evidence to suggest that a growth in renewable energy consumption has an economic impact in the short term. There is evidence which shows there is long term bilateral causality between energy consumption (both renewable and non-renewable) and economic growth. This means that there is a correlation showing increased energy consumption causing economic growth, and economic growth causing increased energy consumption. By using the heterogeneous panel cointegration test at a 1% significance level, it was calculated that a 1% increase in renewable energy consumption lead to a 0.371% increase in real GDP, while a 1% increase in non-renewable energy consumption lead to a 0.384% increase in real GDP, and a 1% increase in the labor force lead to a 0.493% increase in real GDP [1]. The impact on economic growth for renewable energy and non-renewable energy is quite similar. Considering all of the negative impacts of reliance on non-renewable energy such as pollution, volatile prices, and geopolitical conflicts, it would be best to maximize renewable energy growth in developing nations.

There is a conventional view that renewable energy has too high of a startup cost, making it unfeasible, especially for developing nations. This was a primary concern of mine when considering the topic at hand, however there has been extensive research showing the cost of renewables are priced competitively with fossil fuels in Sub-Saharan Africa.

In 2010, wind power at 14-17 cents/kwh was cheaper than diesel at 23-27 cents/kwh when implemented at a large scale [2]. At that time, photovoltaic systems ranged in cost from 66-122 cents/kwh, and wind and solar combined systems ranged in cost from 29-122 cents/kwh. 20-year projections were made for the decrease in costs for these systems based on rates of technological rates. The rates for wind power dropped to 8-9 cents/kwh, rates for wind and solar combined systems dropped to 10-44 cents/kwh, rates for photovoltaic systems dropped to 19-35 cents/kwh, while diesel rates did not change. This takes into account the change in infrastructure cost and efficiency of the technology, while that doesn't change for diesel, this paper did not mention the trajectory of diesel fuel prices over the next 20 years, this could be important. This data is important when considering current and future energy development.

The current grid system in Sub-Saharan Africa is powered mostly by a mixture of fossil fuel sources. This grid system costs about 16-21 cents/kwh for about 90% of Ethiopia's population (the other 10% pays much more in the rural areas). It is useful to compare the current and future cost of energy sources to this grid system cost to see what technologies are the most feasible [2]. With the 20-year projection, about 8% of households are in regions which will have a lower cost of photovoltaic power than grid power, combined solar and wind will be cheaper than the grid for 21% of households. Wind powered systems are projected to be cheapest across the board, however only an estimated one third of household are in supply regions where sufficient winds are present. Similar results were found in other Sub-Saharan countries. This paper concluded that while wind energy costs are low, it usually can only account for a smaller share of a Sub-Saharan country's power. Solar can be used more broadly; however, it is usually more expensive than fossil fuels [2]. There are cultural barriers in some Sub-Saharan countries. A lot of energy consumed in these regions goes towards food preparation. It is common practice for many Nigerians to cook at night to prevent their neighbors from knowing what they are cooking. This has been responsible for failures in previous solar energy endeavors without adequate energy storage [3]. Renewable energy cannot take on the entire demand of Sub-Saharan countries, however it can account for a significant amount of it if planned correctly [2].

Similar analyses were done in South Africa. Most of South Africa is currently powered by coal, as they are the 5th largest exporter of coal worldwide. South Africa is the country with the highest greenhouse gas emissions in Africa. Based on South Africa's location, solar energy holds the highest energy generation potential, while wind holds the second highest potential among renewable energy sources. Despite the fact that South Africa has the greatest potential to generate energy from photovoltaic, most of the recent renewable energy projects have involved wind energy [4]. Despite South Africa's prime abundance of solar radiation, there are many barriers to large scale solar energy production. The government has promised its people to keep energy prices as low as possible, and the price of solar power currently cannot compete with the low price of coal. Another reason is hesitancy from foreign investors. Interviews have been conducted among senior individuals in South African businesses and non-government organizations in regards to the political impacts on renewable energy production. Despite regulators expressing preference for renewable energy publicly, many confusing regulatory signals have been sent out to halt the final components of renewable energy policies, making it more difficult for renewable energy projects to proceed. Almost all public officials are involved in companies which directly deal with the government, making their ties to the coal industry very strong. Many individuals interviewed cannot see the political powers allowing renewables without significant pressure from international powers. The most promising cases for current advancements in renewable energy are in manufacturing clusters. By joining renewable energy and manufacturing, it is easier to gain more backing and get projects to come to fruition quicker [5].

Renewable energy markets are volatile, especially in countries which are new to implementing them. The outcome of a large-scale solar project is unknown and if not done correctly, the consequences would be dire [6]. The best solution this problem involves foreign assistance in both financial and technical training terms. Egypt is one of the leading African nations when it comes to renewable energy. Hydroelectric is the only widely used renewable energy source in Egypt. Energy from solar has a great potential, however there is currently very few solar energy sources in Egypt. The Egyptian government has recently received bids from investors, both local and international, to implement 20 solar energy projects at the cost of $30 billion [7]. Egypt and South Africa are seen as model nations when it comes to implementing renewable energy technology, most of the continent is still far behind. A good example of this is the nation of Nigeria. Only 25% of people living in the capitol have access to electricity, with only 5% of the nation at large has access [8]. This lack of electricity leads most people to unsustainably burn wood for energy, accounting for 90% of the energy produced in Nigeria. Nigeria is a good example of an African nation with a lot of potential for renewable energy without the means to harness it.

While many African governments are making efforts towards building renewable energy infrastructure, there are many barriers which make it difficult to get support from the public and international investors. One major barrier is the lack of knowledge about renewable energy technology and the difference in environmental impact between renewable energy and fossil fuels. A barrier to international investors would be the prevalence of corruption and poor governance among African nations [7]. Solutions to some of these problems include implementing a feed-in tariff, which allows local producers of solar and wind power earn money when they feed power into the grid, and net metering, which gives one credits for future energy usage when one feeds power into the grid. Policies like these would help accelerate the growth of solar and wind power [7]. Another important solution involves resource pooling among African nations. These efforts would involve educating more people faster about energy as well as helping more people get trained in skills which contribute to renewable energy production [8].

While many papers state that the African population is not educated on energy and doesn't understand the benefits of renewables over fossil fuels, one paper seems to contradict that. A paper on Urban and Rural Electrification in Nigeria conducted polls among the public which showed that 87% of Nigerians support renewable energy with the understanding of its economic and national security benefits. A preference ranking showed the Nigerian population preferred solar energy far more than all other energy sources, oil ranking the lowest [9]. These polls were conducted in an oil-rich region of Nigeria. This demonstrates the understanding of the African public on the importance of renewable energy. If these results can be generalized over other regions of Africa, then the barriers to renewable energy would be mostly focused around political negligence, lack of foreign investment, and cost of production.

Since African nations lack the capital to fund the development of large-scale renewable energy projects, these projects are dependent upon foreign investors. Interviews were conducted among stakeholders active in developing nations. The top concern reported by 76% of respondents was political instability, the next concern was financial risk among 63% of respondents, followed by cultural risk among 40% of respondents, and natural risk among 16% of respondents. The most important risks to stakeholders include lack of stable legal framework and bad governance, including corruption and bureaucratic procedures. There are also security concerns of non-government social organizations sabotaging energy infrastructure, terrorism is risk with low likelihood and high consequence [10]. In a different set of interviews, experts were asked to rank the specific political risks based on likelihood. Complexity and corruption of bureaucratic procedures had the highest ranking, followed by instability of national regulations, then absence of guarantees, then low level of political stability, and finally a lack of local government support [10]. A study was done among Moroccan government officials. These officials mostly believed renewable energy could not replace fossil fuels and if it did there could be economic and societal consequences. It should be noted that the vast majority of Moroccan energy is under national control, and perhaps an energy system which incorporated more independent producers would be more welcoming to renewables [10]. The best course of action for changing the minds of these governments would be construct large scale renewable energy projects in the few countries where they are currently feasible and demonstrating their profitability and positive impact on society and the economy.

The current literature well describes which nations have the most potential for specific renewable energy sources. Nations which have begun implementing these technologies are well documented. The risks and setbacks affecting the growth of renewables are also well documented. Political instability and corruption seem to be the biggest barriers to renewable energy growth. There seems to be a lack in literature combining various predictors to help determine how to effectively invest in renewable energy projects. This project seeks to combine predictors deemed important by the literature to determine which predictors are most important when making an investment in a renewable energy project in Africa.

III. DATA DESCRIPTION AND MODEL THEORY

Based on the literature, the strongest predictors for growth in renewable energy infrastructure are the political stability, economic growth (especially in manufacturing), and high energy demand. All of the data collected is for every country in Africa from 2000-2018. Data was collected on total population [11] and urban population [12] from year to year. The urban population was divided by the total population and this number was used for analysis. Data was collected which includes the yearly % change in GDP [13]. This data was chosen to account for economic growth and energy demand. A growing urban population will likely lead to an increase in energy demand and a growing GDP indicates economic growth. To account for political instability, data was collected which gives a yearly score for each country [14]. This score measures the likelihood of political instability and politically-motivated violence occurring in the area. These aggregate scores are given on a standard normal distribution from approximately -2.5 to 2.5, least favorable to most favorable, respectively. Based on insights from the literature, solar energy seems to have the most potential to become widespread in Africa, so a dataset was used which gives the yearly solar power generated in KWH per year [15]. This predictor will likely be affected by a change in the response, so a strong correlation with the response variable likely shows that successful investments lead to more solar generation. The response variable used was the yearly amount of money (in USD) which was invested by foreign agencies in successful renewable energy each year [16]. This number was divided by the total population for the year Since this data was only available from the years 2000-2018 in African nations, all of the predictors were also limited to that timeframe.

The time series data was cleaned, the empty spaces in the predictor values were replaced with the average value for the predictor of its respective country. The political stability data was missing for 2001-2008, so each country's values for those years were replaced with the incremental change from the 2000 value to the 2009 value, assuming a linear trend. There were many missing values in the response dataset, those missing datapoints were assumed to be years for which there were no successful investments and were replaced with 0.

The total population, solar generation, and renewable energy investment variables had values that were far greater than the values of the other predictors. These three variables were scaled to have values ranging from 0 to 10. Having all of the variable within a similar range of values eliminates the problems which occur when algorithms put more weight on values of larger magnitude. Having values of the same magnitude eliminates this effect and allows for more accurate results.

IV. DATA VISUALIZATION

A correlation plot was done for all of the predictors and responses to see if which correlations might be appernet. The correlation plot shown in Figure 1 does not show any notibly strong predictors. It should be noted the short hand for the variables one sees in the plots can be attributed as follows:

Response = yearly USD which was invested by foreign agencies in successful renewable energy each year divided by the total population for the year
GDP_anper = percent change in GDP for the year
Total_Pop = total population
urban_ratio = urban population/total population
Pol_Stab = Political stability score
solar_gen = solar power generated in KWH

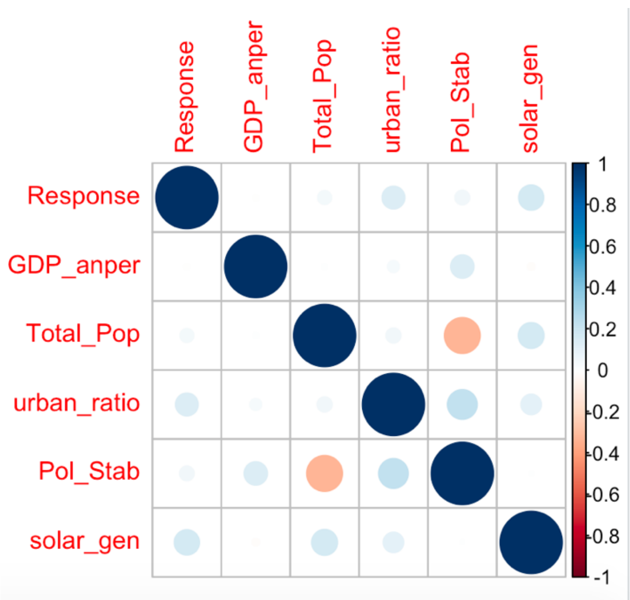

Figure 1: Correlation plot of predictors with response.

The plot shown in Figure 2 shows the response variable plotted for the nations which had the most investments. This plot shows there has been a significant increase in the frequency and amount of investment for most top performing countries from the first half of the time sample to the second half. Most investments in the top nations occur from 2011-2016.

The next three plots shown were generated for the same nations and timeframe as the first plot. Figure 3 shows GDP change vs. time, Figure 4 shows political stability vs. time and Figure 5 shows urban population vs. time. These plots were generated to see if there are any trends which might correlate with the increase of investments seen from 2010-2018. There doesn't seem to be any correlation between GDP and investments. Most nations have an increase in political stability which occurs around 2010-2015, matching the timeframe for most investments. These graphs show a correlation between political stability and investments. The urban population as a fraction of the overall population seems to increase steadily over time for all the nations shown except Egypt. Egypt's decline in urban population likely correlates with their declining political stability. The nations which have the lowest urban population growth seem to have declining political stability. The correlation between urban population and investment does not seem as strong as the correlation between political stability and investment. The general trend of urban population over time does match the general trend of investments increasing over time.

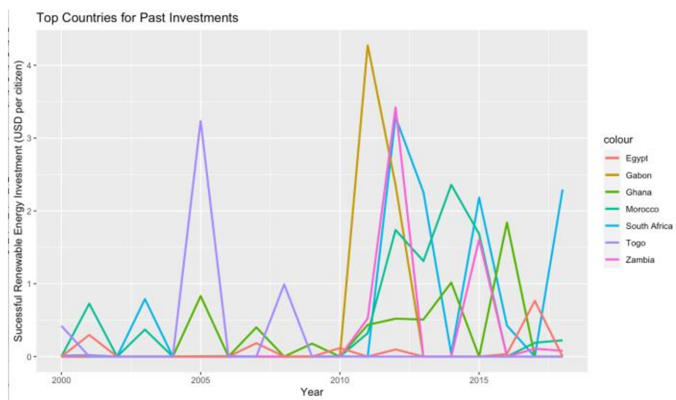

Figure 2: Past Renewable Energy Investments for Top Performing Nations

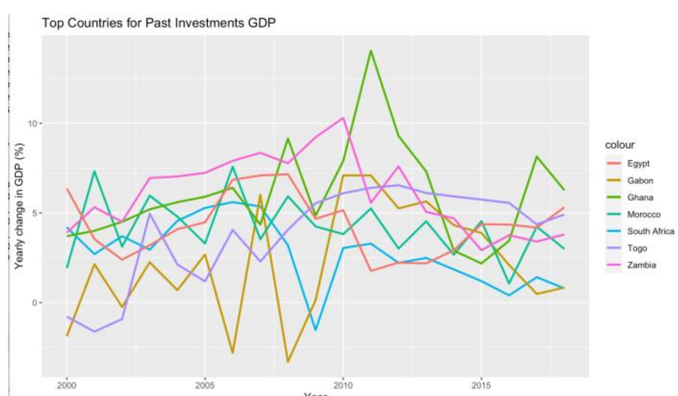

Figure 3: GDP Plot for Top Performing Nations

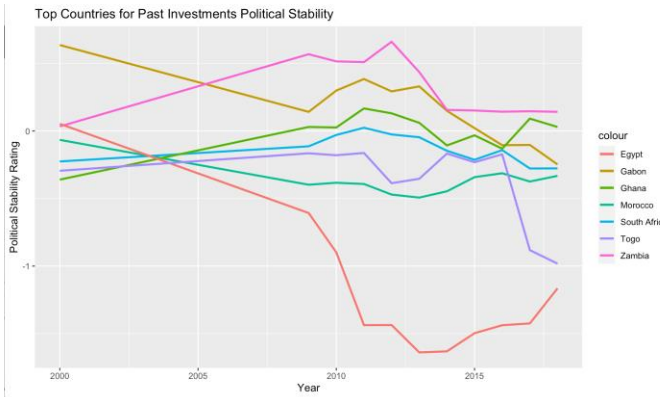

Figure 4: Political Stability Plot for Top Performing Nations

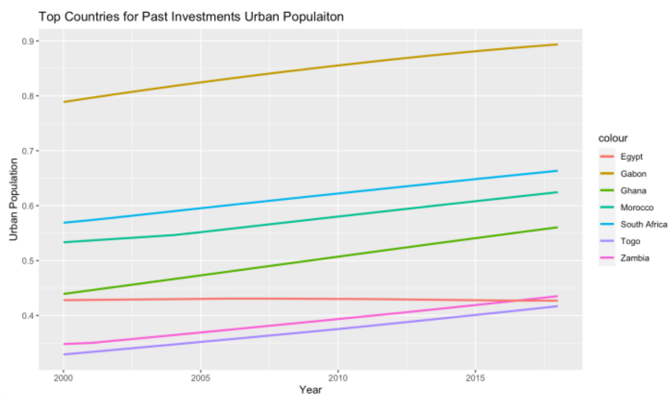

Figure 5: Urban Population Plot for Top Performing Nations.

V. METHODOLOGY

Due to the small size of the dataset, the options for analytical techniques were limited. Supervised learning techniques were used to analyze the dataset. These techniques include a linear model, random forests, bagging, and BART.

The linear model was created in R using the equation [1]

$$Y = \beta_0 + \beta_1 X + \epsilon. \quad \text{Eq. 1}$$

In this equation X represents the predictors and Y is the response variable. A linear relationship is assumed between X and Y.

The bagging method was used in R. The bagging method averages predictions made from B different bootstrapped training data sets (subsets). The model is trained on the b^{th} training subset in order to get $\hat{f}^{*b}$ (x) and the predictions are averaged as shown in equation [2]. The bagging parameters used were number of trees = 3000, number of bootstraps = 500, and min split = 2.

$$\hat{f}_{bag}(x) = \frac{1}{B}\sum_{b=1}^{B}\hat{f}^{*b}(x) \qquad \text{Eq. 2}$$

The random forests method was used in R. Random forest uses a similar approach to bagging, however random forests decorrelates trees. Random Forests uses bootstrapping on the training samples, and it also chooses a random set of m predictors from the set of p total predictors each time a prediction is made. Typically, $m = \sqrt{p}$. The random forest parameter used in R was a number of trees = 4000. It should be noted that many different parameters were tried for bagging and random forest and the parameters chosen resulted in the most accurate results and relatively low run time.

Bayesian Additive Regression Trees (BART) was used from the R package bartMachine. BART uses probability that a node will be split at a specific depth, a distribution used to select which covariate the node will be split upon, and a distribution to find the point at which the node will be cutoff to control tree complexity when building an additive tree. This is shown by equation [3].

$$Y = g(x; T_1, M_1) + g(x; T_2, M_2) + \cdots + g(x; T_m, M_m) + \epsilon$$
$$\text{where } \epsilon \sim N(0, \sigma^2). \quad \text{Eq. 3}$$

These models were chosen to be used for determining the strength of the correlation between the predictors and the response. Attempts were made to forecast the response for future years, one of the methods used in this attempt was BART. The issue was that the dataset used is not large enough for forecasting to work, so this research is limited to finding correlations and determining predictor strengths.

VI. RESULTS

After running the visualizations, the dataset was split into 80% training data and 20% testing data. The training data was used to train all the models. Training and testing root mean squared error (RMSE) was calculated for each model and shown in Table 1.

MODEL (DEPRESSION)	TRAINING RMSE	TESTING RMSE
LINEAR MODEL	0.527	0.250
BAGGING	0.227	0.339
RANDOM FORESTS	0.276	0.299
BART	0.300	0.507

Table 1: Test and Train RMSE for Each Model

The quantile-quantile plots (Q-Q plots) shown for each model are in Figures 6, 7, 8, and 9. These plots plot 2 distributions against one another. The closer the distributions are to being identical, the closer the plot of residuals will be to resembling a straight line. This is useful for visualizing how close the predicted values from a model are to the actual testing data.

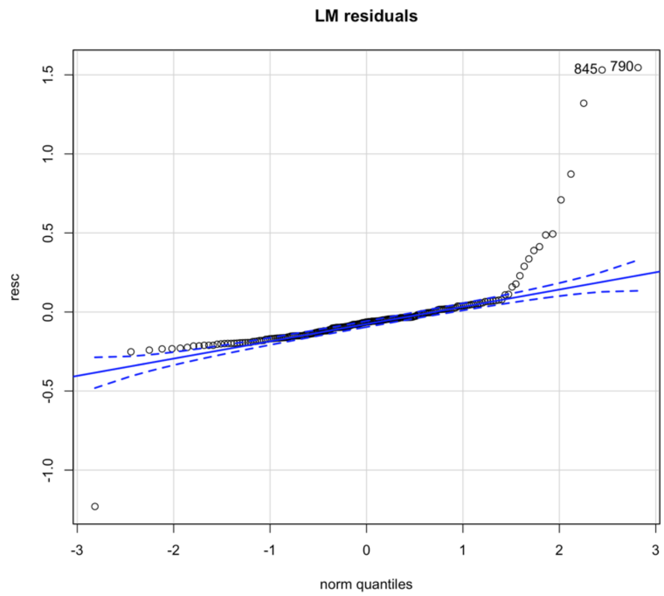

Figure 6: Q-Q Plot for Linear model

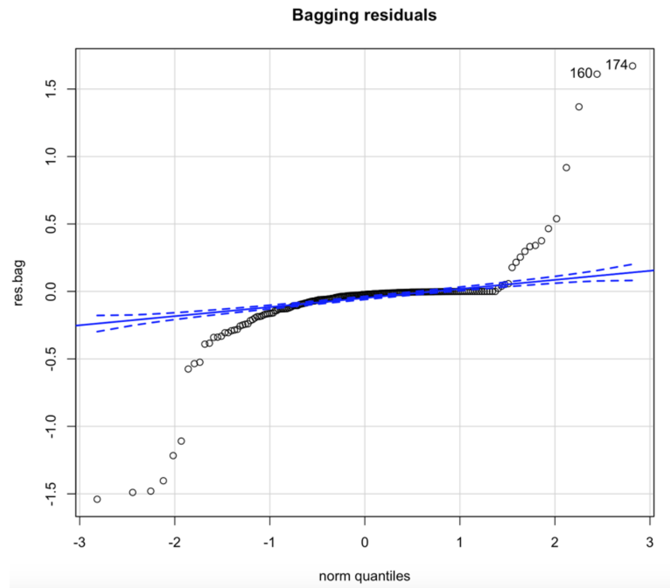

Figure 8: Q-Q Plot for Bagging

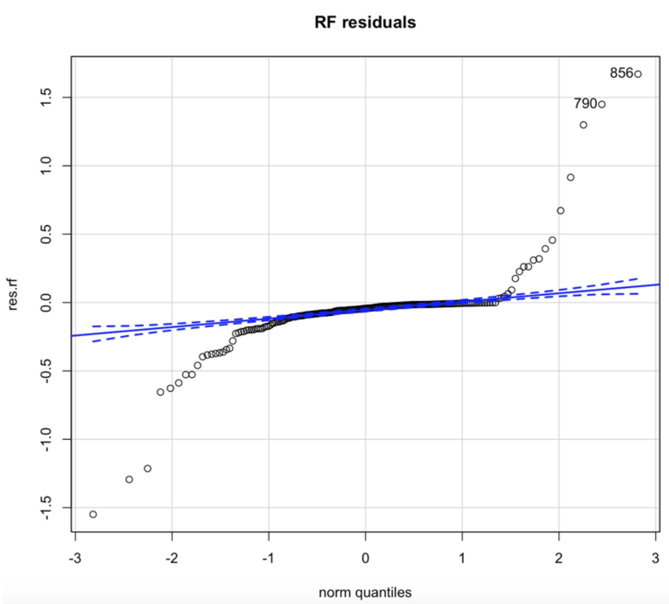

Figure 7: Q-Q Plot for Random Forests

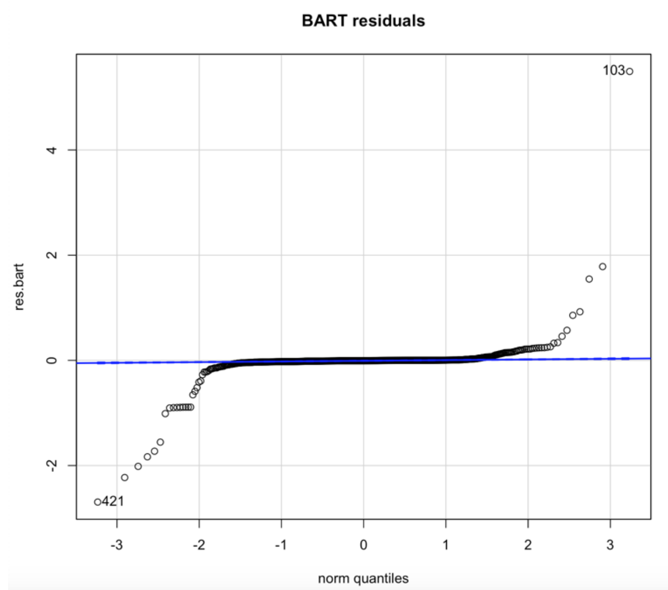

Figure 9: Q-Q Plot for BART

The variable importance charts are shown in Figures 10, 11, and 12. They show the relative importance of each predictor used in their respective model to predict the response. The higher the overall importance of the predictor, the better it was at predicting the response for that given model. Figure 13 shows the inclusion proportion of the predictors for predicting the response for BART. The predictors with the highest proportion were most influential for the prediction.

	Overall
GDP_anper	0.2870784
Total_Pop	0.6247911
urban_ratio	2.3285498
Pol_Stab	2.3109002
solar_gen	4.2063764

Figure 10: Variable Importance for Linear Model

	IncNodePurity
GDP_anper	34.86331
Total_Pop	47.74280
urban_ratio	46.15815
Pol_Stab	37.36706
solar_gen	31.12399

Figure 11: Variable Importance for Random Forests

	Overall
GDP_anper	47.73758
Pol_Stab	48.99096
solar_gen	37.90470
Total_Pop	50.80622
urban_ratio	49.51511

Figure 12: Variable Importance for Bagging

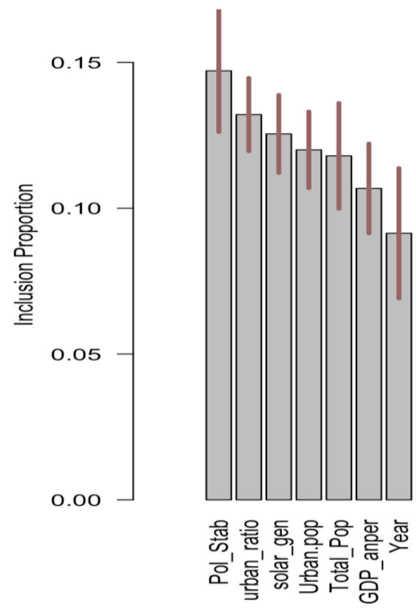

Figure 13: Inclusion Proportion for BART

VII. DISCUSSSION AND CONCLUSION

This research was conducted to determine which predictors could have the most influence on foreign agencies investing in renewable energy projects in Africa. A literature review was conducted to determine which predictors would likely be the best for useful insights into this difficult challenge. These predictors were used in the four different models discussed in this paper.

The observer of the results from these models must keep in mind that the dataset was relatively small. Some of the issues that can result from this include; outliers throwing off results and overfitting. Table 1 shows the training error of 0.527 for the linear model is much higher than the testing error of 0.25 for the linear model. This result is likely because of the small size of the dataset. The outliers in the training data are likely leading to greater error, since the testing data likely has far less outlier, the error is lower.

The linear model had the lowest testing RMSE and its Q-Q plot had the best linear fit compared to all the other models. The testing error for random forests and bagging were only slightly higher at 0.299 and 0.339 respectively. They both had lower training errors at 0.276 and 0.227 respectively. Their residual points on their Q-Q plots were not as linear as the points on the linear model. BART had significantly higher testing error at 0.507 with a training error of 0.30. The residuals on its Q-Q plot formed a more linear pattern than that of bagging and random forests, however it had more extreme outliers. The linear model gives solar generation as the best predictor (t score of 4.21), followed by urban population (t score of 2.33) and political stability (t score of 2.31). Total population (t score of 0.62) and GDP (t score of 0.29) did were much less influential to the linear model.

Bagging and random forests gave similar results on variable importance. Total population and urban ratio were the most influential in both. Total population and urban ratio have a node purity of 47.7 and 46.2 respectively for random forests and 50.8 and 49.6 respectively for bagging. Political stability was third most important for both, being much more important in bagging (49.0) than random forests (37.4). The GDP and solar generation were fourth and fifth in both. BART had political stability as its most influential predictor, followed by urban population and solar generation.

Due to the small size of the dataset, it is difficult to determine if there is a best model, there are tradeoffs between all of them. Without more data, the best that can be done it to derive conclusions from a combination of the results. To determine a rough estimation of the variable importance across the four models, a ranking system was used. For each model, a ranking score was given to each predictor from 1 (least influential) to 5 (most influential). After tallying the scores over the four models, urban population ratio has a score of 16, political stability has a score of 14, total population has a score of 14, solar generation has a score of 10, and GDP has a score of 6. Total population is the most important predictor in bagging and random forests, and second to least important in the linear model and BART. Political stability seems to be relatively important in every model, it has the highest importance in BART and is very important in bagging. By looking at the model with the lowest testing error and best Q-Q plot, the linear model, political stability is a more important predictor than total population.

Based on these results, urban population seems to be the most important predictor of foreign investments. The political stability seems to be the second most important predictor of foreign investments. GDP had the least influence on foreign investments. These results seem to match graphs shown for the top invested countries in Figures 2-5. These results indicate that the biggest predictor of a country receiving a successful renewable energy investment are the demand for energy driven by a growing urban population. These results also show that it is important that the more politically stable a country is, the more likely it is to receive investments in renewable energy. The GDP of a country does not seem to be a good predictor of the country receiving an investment. Based on these results, it would be advisable to invest in a renewable energy project in a nation which has a growing urban population and is politically stable, regardless of its GDP. This conclusion is based on research on limited data, and any agency seriously considering these investments would be advised to purchase larger, more comprehensive datasets and run similar models to get a more detailed look at predictors which predict the best places for investments.

One setback to this analysis is the fact that not all of the important predictors for this issue can be easily quantified into comprehensive datasets. An example of this is the fact that Nigeria has great potential for photovoltaic power, its citizens consume most of their power at night, as it is a cultural practice to cook most their meals after sun down. This is a very important issue when an investor is considering the risk of investing in solar power in Nigeria. If that investor only looked at the numerical predictors of the nation such as political stability and urban population, they could miss key predictors in the success of their investments. This makes it exceptionally difficult to make blanketed decisions based on this data. While these trends are useful, an investor must do extensive research into the cultural practices of a region before seriously consider investing in it. This is a challenging risk analysis problem and this research is only part of the information one must consider before making decisions in renewable energy infrastructure investments.

VIII. Future Research

The data sets used for this project were all found from various free sources. There seem to be more complete and comprehensive datasets which would serve as better predictors. These data sets required payment for access, so they could not be used in this project. The datasets used to create the overall dataset were carefully researched to be the most useful and informative. If a budget is obtained for future research, access to these more comprehensive datasets would allow for a more detailed analysis. These datasets could include longer timeframes for the predictors and response, more location specific data, broken up by city or region instead of by country, and more useful predictors, such as detailed analysis of solar and wind data. It would also be useful to create a dataset which accounts for cultural aspects of a region and their impact on energy usage. This data would likely be categorical in nature, and could provide further insights.

With a larger amount of data, future research could involve the use of forecasting methods to determine which African regions might be best to invest in for future years. Research suggests that improvements in one nation can lead to improvements in neighboring nations. Future modeling could include predictions on how heavily investing in one nation could improve the conditions of neighboring nations. This could result in possible timelines for investors to follow. So long as the predictors and values are relevant to the problem one is studying, having a larger dataset will lead to better, more comprehensive results. There are more possibilities for modeling and analysis using a much larger dataset.

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