The Impact of Low Electricity Prices on Renewable Energy Production

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***Abstract*—Many countries are actively developing plans to increase renewable energy production with some countries even targeting a goal of 100% renewable energy within the next few years. The reasons are twofold, reduced carbon emissions and reduced dependence on fossil fuels with the associated fluctuations in oil and natural gas prices. However, several other countries have not been taking the required actions to increase their production of renewable energy. In some cases this occurs in energy-rich countries where electricity prices are heavily subsidized and hence residential and commercial consumers have no incentive to invest in renewable energy because the time taken to offset the investment is far too long. We use Machine Learning techniques to quantify this conjecture by showing the relationship between renewable energy production and electric prices for various countries. The data used for this exercise (namely electricity costs and renewable energy production per country) is taken from various online datasets. We conclude that, in order for a country to seriously increase its renewable energy production so that it is a significant percentage of total energy production, it must first reduce the heavy subsidies provided to its citizens. Using our model we can determine, for a given country, what reduction in subsidies is required to achieve a certain renewable energy production target. Countries can then use this information to plan future renewable energy targets and electricity subsidy reductions. We use our home country as a use case for this exercise.**

***Index Terms*—Renewable Energy, Electricity Pricing, Energy Policy, Regression**

I. Introduction

In recent years several countries have set targets for renewable energy production. The need to reduce carbon emissions and hence reduce the effect of these on climate change has been one driving force. Countries have made commitments under international agreements such as the Kyoto Protocol and the Paris Agreement to limit their carbon emissions, to which fossil fuel-based electricity generation is one of the most significant contributors. In addition, the dependence on fossil fuels can sometimes be challenging for countries, especially those such as energy-importing small island developing states (SIDS), due to high transport costs as well as frequent fluctuations in energy commodity prices, i.e., the prices of coal, oil and natural gas. Finally, the use of environmentally-friendly, sustainable, renewable energy is likely to lead to a more stable energy production environment for most countries, especially as the storage technology for such forms of energy become more reliable, with higher capacity and at lower cost.

In order to invest in renewable energy, countries must have incentives to reduce their reliance on fossil fuel sources. In particular, if electricity prices are low then consumers are less likely to invest in sources such as solar energy since the payback period (i.e., the time over which the experienced savings exceeds the initial investment) can be quite long. Therefore, renewable energy production is affected by electricity prices. Compounding this situation, in many fossil fuel-rich countries, electricity is subsidized by the Government, thus taking its price far below market value. In such countries investment in renewable energy tends to be low. We conjecture that there is a relationship between electricity prices and renewable energy production and we illustrate that relationship in this paper. This relationship between electricity prices and renewable energy production can be used by Governments in energy-rich countries to determine how much electricity prices and subsidies should be adjusted if a specific renewable energy production target is to be achieved. We illustrate this using a use case for the twin-island nation of Trinidad and Tobago.

II. Contributions and Related Work

In the literature, there has been some research on the relationship between renewable energy and electricity prices especially in European countries, but with the direction of implied causality running from renewable energy measures to observed prices. For example, [1] uses daily wind speed readings from the Netherlands and Germany, and sunshine intensity readings from the Netherlands to estimate whether increased Dutch renewable energy production capacity over the period 2006-2011 contributed to variability in daily electricity prices.

The authors in [2] argue that, although electricity markets around the world have become increasingly deregulated and price variability has accordingly risen, the characteristics of renewable energy generation technologies suggest that a greater contribution of renewable sources to overall production would lead to a mitigation of this price variability by expanding supply at the base of the total electricity supply curve. According to this argument, the implications of lower price volatility should be positive for renewable energy investors - due to more predictable returns - as well as consumers who would benefit from lower prices and risk. [3] provides an empirical exploration of Danish and German wind and solar examples to also estimate the impact of renewable sources on electricity price levels and volatility finding that renewable sources decrease price levels while each country had contrasting experiences with respect to pricing volatility. Danish wind power increased volatility by smoothening hourly prices but German wind power increased volatility via its impact on off-peak prices.The authors of [4] construct historical supply and demand curves based on German spot price data from 2011-2013 to estimate that the high share of renewable sources in Germany's power generation system was not the cause of rising electricity prices over that period.

It is important to note that the above papers reference countries in which electricity prices are dynamic and can fluctuate throughout the day. In [5] the authors investigate the impact of different electricity pricing policies, i.e. flat pricing vs. peak pricing, on investments in renewable energy from the perspective of both utility providers and distributed generators (e.g., residential customers with home solar panels). They find that flat pricing is more conducive to investment in renewable sources (solar and wind) by utility providers, whereas peak pricing induces greater investment in solar capacity by distributed generators. These results are noted in the context of Trinidad and Tobago, where electricity prices are administered on an increasing block tariff (IBT) basis with multiple incremental pricing tiers based on the volume of consumption, as well as an access charge.

There is another line of research in the literature examining the factors that influence countries levels of investment and in renewable energy research and development (R&D). For example, [6] finds that electricity consumption drives wind energy R&D but has less of an effect on solar R&D in China. Surprisingly, lower electricity prices induced higher R&D spending on all forms of renewable sources while subsidies for renewable R&D had negligible impact.

III. Datasets

We obtained the data for electricity prices from [7]. The data (in terms of the average electricity price in USD per kWh for each country) from this source is very current (June 2018) and the methodology used to collect price data is quite robust and is based on the electricity prices offered by companies in each country corrected for the market shares of the companies, distribution fees, regulatory and tax environment, etc. Unfortunately, data from only 63 countries are included but these are sufficient to illustrate the relationship we advance in this paper.

We obtained data on renewable energy from the site [8]. This site has a rich set of data on production capacities per energy source for various countries. For each country it provides, as a percentage of the total production capacity, data for Fossil fuels, Nuclear power, Water power, Renewable energy and Other energy sources. According to their web site "Renewable energies include wind, solar, biomass and geothermal energy sources. This means all energy sources that renew themselves within a short time or are permanently available. Energy from hydro-power is only partly a renewable energy. This is certainly the case with river or tidal power plants. Otherwise, numerous dams or reservoirs also produce mixed forms, e.g. by pumping water into their reservoirs at night and recovering energy from them during the day when there is an increased demand for electricity. Since it is not possible to clearly determine the amount of generated energy, all energies from hydro-power are displayed separately". Because of this reason we do not include water power (which includes hydro-power) in our analysis but simply use the renewable energy data (as a percentage of total production capacity). One should however note that in some countries (such as Canada and Brazil), hydro-power is heavily used and so in such countries there is a lesser need to invest in renewable energy and so such countries may not conform to our conjecture.

Also note that our interest is renewable energy investment but we believe that renewable energy production capacity is closely related since it serves as a reasonable proxy given that it reflects past investment in renewable energy. The data collected from these two sources are displayed in Table I. We have added one other country (Trinidad and Tobago) which was not included in the list obtained from [7]. The electricity price for this country was obtained from current Government information and the renewable energy value was obtained from [8].

When this data was first plotted (renewable energy versus price) we visually observed three outliers. Denmark and Germany both have high renewable energy production values (53.6% and 49.9% respectively). At such high values we do not believe that our conjecture holds because as the initial costs of investing in renewable energy is covered and dependence on fossil fuels is reduced then electricity prices should once again start to decline. These two countries illustrate this effect and so were not included in our analysis. In addition, we find for Bermuda a high electricity price of $0.387 per kWh while their renewable energy production capacity was zero. However, based on information on their Government's website, significant progress is being made in building renewable energy capacity. Hence this is an example in which the provided renewable energy production capacity data did not reflect observed investment and therefore the data for Bermuda was not used in the analysis. Summary statistics on this data are presented in Table II.

IV. Analysis

The data from Table I (except for the 3 outliers) are plotted in Figure 1. We can see that there is a relationship between renewable energy production and electricity price. We used linear regression to obtain the best linear fit and this is plotted as the red line. The equation for the line of best fit is given as:

$$\text{Renewable Energy} = -2.9 + 93.9\ (\text{Electricity Price}) \quad (1)$$

Therefore we find that each 10 cent/kWH increase in price results in an increase in renewable energy capacity of about 9.4%. The r-value (i.e., the Pearson correlation coefficient between the two variables in the dataset) is evaluated as **0.73**

TABLE I
COUNTRY DATA FOR RENEWABLE ENERGY (PERCENTAGE OF TOTAL PRODUCTION) AND ELECTRICITY PRICE (IN USD PER KWH)

Country	Renewable Energy	Electricity Price
Algeria	1.5	0.038
Argentina	2.5	0.162
Aruba	12.8	0.203
Australia	16.1	0.27
Austria	24.3	0.223
Bangladesh	1.6	0.058
Barbados	8.1	0.284
Belgium	32.1	0.312
Belize	19.4	0.203
Bermuda	0	0.387
Bolivia	8	0.118
Brazil	16	0.181
Canada	11.4	0.107
Chile	16.1	0.201
China	13.7	0.086
Colombia	1.6	0.163
Croatia	12	0.166
Czech Republic	14.5	0.23
Denmark	53.6	0.375
Egypt	2.2	0.018
Finland	23.5	0.194
France	16.9	0.19
Germany	49.9	0.35
Greece	26.8	0.209
Hong Kong	0	0.138
Hungary	14.1	0.139
India	14.6	0.079
Indonesia	5.9	0.104
Iran	0.2	0.027
Iraq	0	0.008
Ireland	29.7	0.278
Israel	4.9	0.155

Country	Renewable Energy	Electricity Price
Italy	28.6	0.241
Japan	15	0.266
Luxembourg	12.7	0.212
Macau	0	0.152
Malaysia	4	0.061
Mexico	8.5	0.081
Netherlands	22	0.223
New Zealand	19.7	0.205
Nigeria	0.2	0.077
Norway	3.3	0.16
Pakistan	5.7	0.075
Peru	4.3	0.197
Philippines	15.6	0.188
Poland	18.8	0.175
Portugal	32.5	0.299
Qatar	0.5	0.026
Russian Federation	0.6	0.066
Saudi Arabia	0.1	0.048
Singapore	1.9	0.165
Slovak Republic	11.8	0.177
Slovenia	1.7	0.203
South Africa	7.1	0.163
South Korea	7.2	0.117
Spain	29.5	0.267
Sweden	30	0.196
Switzerland	11.1	0.198
Taiwan	5.4	0.094
Thailand	14.2	0.117
Trinidad and Tobago	0.4	0.05
Turkey	11.2	0.104
United Arab Emirates	0.5	0.078
United Kingdom	33.4	0.224

indicating strong positive correlation between electricity prices and renewable energy investment. Finally, the coefficient of determination, R^2 is evaluated as **0.53**. Roughly 53% of the variation in renewable energy capacity in the dataset can be explained by variation in the price of electricity for the countries in question. The p-value for this regression is computed to be $2.81e^{-11}$, and this value is less than the threshold value of 0.05 and so the relationship is held to be statistically significant.

V. USE CASE EXAMPLE: TRINIDAD AND TOBAGO

The Government of the Republic of Trinidad and Tobago has set a renewable energy target of 10% by 2021. From [9] we found that the average cost for electricity is US $0.047 per kWh and from [8] we find that 0.4% of energy produced in Trinidad and Tobago is derived from renewable sources. Assuming the same rate of change as computed in 1 this would mean that, in order to incentivize a renewable energy rate of 10%, electricity price must be increased by 9.1 cents/kWh to US $0.138 per kWh, or an increase of approximately 176%. This can be achieved by increasing the average price by roughly 3 cents/kWh in each of the years 2019, 2020 and 2021. Note that these may seem like drastic increases but this is only because the present price is heavily subsidized by the government at present.

Let us now consider the effect of electricity subsidies.

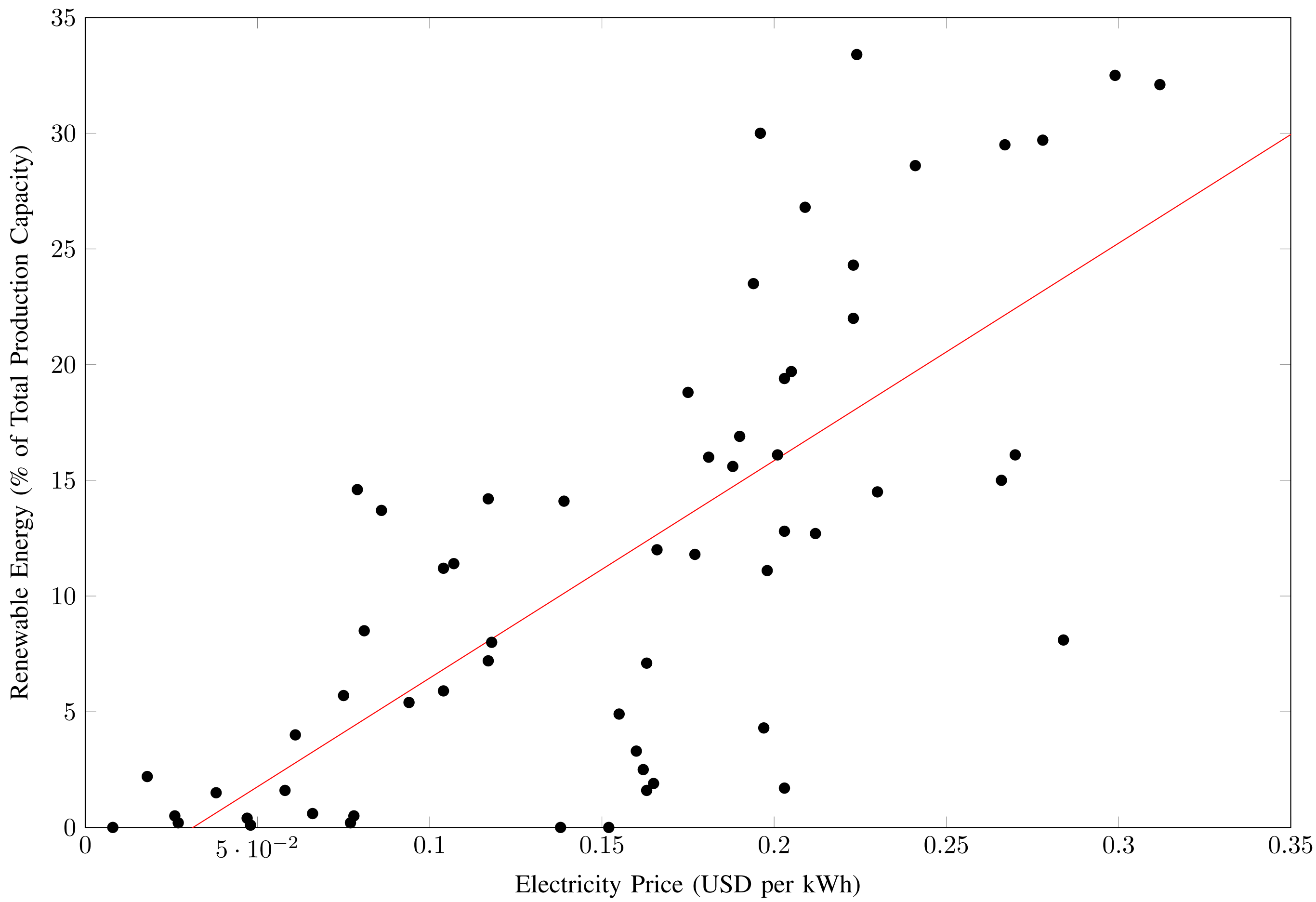

Fig. 1. Renewable Energy versus Electricity Price

TABLE II
SUMMARY STATISTICS OF COUNTRY DATA IN I

Statistic	Renewable Energy	Electricity Price
Mean	11.61	0.16
Standard Deviation	9.95	0.08
Min. Value	0.00	0.008
25%	2.20	0.086
50%	11.20	0.16
75%	16.10	0.203
Max. Value	33.40	0.31

The unsubsidized cost of electricity of other islands in the Caribbean are significantly higher, e.g. Barbados ($0.28), Jamaica ($0.32), Grenada ($0.43), St Lucia ($0.34), Bahamas ($0.32), Antigua ($0.37) and Dominica ($0.38). These countries' electricity prices figure among the highest in the world. The average of these countries' electricity prices is $0.35. In Trinidad and Tobago, conversely, electricity prices (as well as vehicular fuel) are subsidized by Government, which cost the state US $187.3 million in 2016, according to [10]. The unsubsidized cost of electricity in Trinidad and Tobago is estimated to be $0.12 per kWh, and as stated above the subsidized price is $0.047, meaning roughly 61% of the cost is subsidized. If the electricity price is increased by 9.1 cents/kWh to 13.8 cents/kWh to achieve a renewable energy production of 10%, this would involve the complete removal of the electricity subsidy over the three year period and an increase in price to 1.8 cents/kWh above the estimated production cost, assuming no changes in production costs.

We can use our analysis to propose how electricity pricing should be adjusted to achieve the renewable energy goal of Trinidad and Tobago. Table III shows suggested rates for residential electricity pricing in Trinidad and Tobago, based on the 2017 rate schedule outlined in [9] and the output of the model.

It is important to also note that the other Caribbean countries cited in the example above are all net energy importers, whereas Trinidad and Tobago has traditionally been a net energy exporter (though fossil fuel exports have declined in recent years and imports have risen). From the country data, one can observe at a glance that the countries with the lowest electricity costs - at the bottom quartile ($0.086) or below - include mainly net fossil fuel exporters

TABLE III
PREDICTED RESIDENTIAL ELECTRICITY PRICES (IN USD PER KWH) TO ACHIEVE A RENEWABLE ENERGY TARGET OF 10% IN 2021

Range	**2018**	**2019***	**2020***	**2021***
1-400 kWh	0.039	0.064	0.089	0.113
401-1,000 kWh	0.048	0.078	0.109	0.139
Over 1,000 kWh	0.055	0.09	0.126	0.161

such as Iraq ($0.008), Egypt ($0.018), Qatar ($0.026), Iran ($0.027), Algeria ($0.038), Saudi Arabia ($0.048), Trinidad and Tobago ($0.047), Malaysia ($0.061), Russia ($0.066), Nigeria ($0.077), United Arab Emirates ($0.078) and Mexico ($0.081). The only exceptions to this trend were very large, populous countries in Asia such as Bangladesh ($0.058), Pakistan ($0.075), India ($0.079) and China ($0.086). With the exception of Malaysia (4.0%), all of the quoted fossil fuel exporting countries were also at or below the 25th percentile with regard to renewable energy production capacity.

As is the case for Trinidad and Tobago, the majority of fossil fuel exporting countries quoted above (as well as China, India and Bangladesh) subsidize their electricity production heavily [10], contributing to their low electricity prices and corresponding low levels of renewable energy production capacity. It is also interesting to note that Norway, a fossil fuel exporting country with unsubsidized and therefore relatively higher electricity prices ($0.16) still has quite low renewable energy capacity (3.3%), especially when compared to its nearest neighbors such as Sweden (30%) and Finland (23.5%). One conclusion to be tentatively drawn from these observations is that while low electricity prices do indeed create disincentives to renewable energy investment, and these disincentives are compounded by electricity subsidies, fossil fuel production itself may create some subtle barriers to renewable investment, even when low prices and subsidies are not observed.

VI. CONCLUSIONS AND FUTURE WORK

In this paper we conjectured and then illustrated a linear relationship between electricity prices and renewable energy investment, as measured by proxy through current renewable energy capacity. This relationship is determined to be strong and positive though there would certainly be a number of other pertinent factors that influence renewable energy investment. In addition, we conjecture that at high levels (greater than 50% of total production) of renewable energy investment our proposed relationship no longer holds. At those levels of investments (e.g., in Denmark and Germany) the mature deployment of renewable energy sources start to cause a reduction in electricity prices. Hence our study investigates the effect of pricing on renewable energy production but as production levels increase electricity prices are in turn affected (decreased) because of the reduced dependence on fossil fuels. Therefore, for such countries, we believe that a more sophisticated model is needed. Although one can propose such models, because few countries are presently in that range of renewable energy investment, there would be insufficient data to validate the model.

Our future work will also include the inclusion of other significant features that likely affect renewable energy investment. In particular, a country's Gross Domestic Product (GDP) per capita, is expected to be influential since it reflects the country's economic capacity to invest in these technologies. While poor and middle-income countries, especially the SIDS such as the Caribbean countries, face above-average electricity costs and therefore would reap significant benefits from alternative energy sources, they may not have sufficient financial resources either in the public or private sectors to spend on building this capacity in the absence of external support. In such situations, the relationship described in this paper would be weakened. With more comprehensive and reliable renewable energy and electricity price data on these countries we would be able to explore these cases in more detail. Furthermore, the structure of electricity pricing within countries has an influence on renewable energy investment as shown in [5]. Given that several pricing models exist around the world it may be fruitful to explore its impact across countries.

Given the strong relationship observed between fossil fuel exporters and low electricity prices outlined in Figure 1, future work will also include indicators such as fossil fuel exports as a proportion of GDP. Moreover, while we briefly examined the effect of subsidies for fossil-fuel based electricity generation on electricity prices, and thereby on renewable energy investment, it will also be interesting to observe how a country's renewable energy incentive regimes (tax breaks and subsidies) affect their investments especially as many governments will soon have to increase renewable capacity to meet national policy targets and international obligations.

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