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ELECTRICITY PRICE FORECASTING OF FOSSIL FUELS AND RENEWABLE SOURCES IN COMPETITIVE POWER MARKETS

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Abstract
The seasonal fluctuations and weather problems are the causes of high volatility in electricity prices. The restriction of data, stochastic change in demand and supply, and sensitivity of models further hinder the electricity price forecasting accuracy. Accurate forecasts assist producers, retailers, and consumers optimize the profits and reduce the costs of electricity. The proposed study aims to forecast the electricity price in all continents (Asia, Africa, Europe, America and Oceania) using the Low Emission Analysis Platform (LEAP) software. The results shows that the electricity price statistics of fossil fuels and renewables for the year 2025 and 2030 and presented the country wise analysis in each continent. Solar based electricity will be expensive in Asia (150 USD/MWh) in 2030, wind electricity will be expensive in Africa (230 USD/MWh) in 2030, biomass electricity will be expensive in Asia and Africa with same cost 120 USD/MWh in 2030, nuclear and geothermal electricity will be expensive in Africa with 110 USD/MWh and 105 USD/MWh in 2030. Alongside, coal, natural gas, furnace oil and hydro power will also be expensive in Africa with 130 USD/MWh, 230 USD/MWh, 210 USD/MWh, and 80 USD/MWh respectively in 2030. It is concluded that, this study helps to achieve sustainable electricity price forecast with high accuracy.

I. INTRODUCTION

Electricity price forecasting as a field of study in its own right emerged in the early 1990s with the liberalization and deregulation of the electricity sector in the United Kingdom (UK) and Scandinavia [1]. The late 1990s and 2000s were marked by the widespread transformation of the traditionally monopolistic, government-controlled electricity sectors into competitive electricity markets in Europe, North America, Australia, and eventually Asia [2]. Over the years, electricity price forecasting has become a fundamental part of business decision-making [3]. For a medium-sized utility with an annual peak load of 5 GW, an improvement in the daily demand forecast by 1% results in annual savings of USD 1.5 million [4]. With price predictions the utility's savings will be double. Clearly, the time invested in developing electricity price forecasting models can pay off. In today's increasingly complex global electricity market environment, trying to forecast power expenses is crucial for all marketplace actors. However, the power expenses differ in different commodities [5].

In addition to the growth of smart grid initiatives, the deregulated electricity market is becoming more common. An electric power market based on fixed prices follows a distinct and more or less regular peak demand curve [6]. In order to meet this peak demand, the supplier is forced to utilize resources, and these resources will be redundant for the rest of the time [7]. Under the Smart Grid initiative, a demand-side management concept is proposed to overcome this inefficiency. The smart grid enables two-way communication between energy suppliers and consumers. This decentralized online flow of information allows the provider to charge consumers based on their feedback [8]. On the one hand, consumers can program their spending behavior to achieve optimal usage at the lowest possible cost [9]. A supplier's main concern is to create a healthy balance between supply and demand [10]. The general idea of demand management is to develop hourly pricing mechanisms that can persuade consumers to change their usage patterns to reduce peak demand. A consumer has access to a retail electricity market and can choose when to purchase the desired amount of electricity from the market [11]. As a result, a cost-conscious client will be fascinated in the achievable electrical energy costs in the coming hours, days, or even weeks, and will attempt to optimize his/her utilization and minimize the complete invoice through clever electrical energy usage.

Electricity rate forecasting is equally necessary for different energy users in the liberalized electrical energy market, such as wholesalers, traders, and retailers [12]. The potential to precisely forecast future wholesale electricity costs will enable them to design successfully and function efficiently, which will finally translate into economic advantages for them [13]. As a result, the rate of energy is a whole lot more volatile than the load, resulting in charge spikes every now and then. Prices of fossil-derived electricity at the global scale fluctuate by region, type of fuel, and market circumstances. In some regions with coal such as parts of China, India and the United States, coal-fired generation is the lowest-cost fossil source, and its cost is 0.05 to 0.10 USD/kWh, and is supported by an already-established infrastructure, but is challenged by carbon pricing and phase-out regulations that may impose an extra 0.02 to 0.05 USD/kWh in emissions costs [14]. In gas-rich areas such as the Middle East, North America and Russia, lower capital costs and increased efficiency ensure competitive prices of natural gas combined-cycle plants of between 0.04-0.08 USD/kWh. In isolated grids such as islands or remote regions in Africa and the Pacific, oil-based generation is the most common because of its high fuel costs (0.150.30 USD/kWh) [15].

The cost of electricity of renewable sources has dropped all around the world, and thus in most places, they are the lowest new-build power sources [16]. Utility-scale solar photovoltaic costs are at an average of 0.049 USD/kWh, onshore wind is at an average of 0.033 USD/kWh, and offshore wind is at an average of 0.075 USD/kWh unsubsidized and competing with or at or below fossil fuel options such as coal and gas combined cycle [17]. These are significant declines of the cost of solar, down 89% since 2010, as a result of technology, economies of scale, and efficiencies in the supply chain, but these numbers vary depending on location due to resource quality, cost of financing (cost in developing countries such as Pakistan is 10 to 15 percent versus 3 to 5 percent in Europe), and grid integration requirements. The geothermal and hydropower are currently at 0.056 to 0.111 USD/kWh and 0.037 to 0.106 USD/kWh respectively underlining the renewable domination in the energy transition as the volatility in fossil fuels increases [18]. Hence the major contribution of the proposed study is to forecast the electricity price of all the continents like Asia, Africa, Europe, America and Oceania using the Low Emission Analysis Platform (LEAP). The study identified the maximum and minimum electricity price statistics of fossil fuels and renewables in each continent and presented the country wise analysis where the price is greater or lower.

II. RESEARCH METHODOLOGY

In our proposed work, the Low Emissions Analysis Platform (LEAP) is used to forecast the electricity prices in all the continents of the world like Asian, African, European, American and Ocenaia continents. The research flow diagram is shown in Figure 1. The LEAP software is the bottom up accounting framework that is particularly useful for forecasting energy demand, generation, carbon emissions and electricity prices [19]. It should also be noted that LEAP is used by government institutions, non-governmental organizations, academics, consultants, and utilities. The use of LEAP does not require the user to be a professional in programming or to own a sophisticated computer. This has a very simple graphical user interface for data input and data editing which fits very well with countries with low volumes of data and low technical skills [20]. Furthermore, it delivers fast computations, which allow for an efficient iterative model estimation that is based on accumulating new information.

The LEAP software is equally suitable in estimating energy related and non–energy related carbon emissions. It is also possible to analyze the energy data having any time periods using the "time slices" defined by a user. It allows the exploration of the periodic pattern of energy demand and supply that is vital in forecasting and planning the energy usage. With respect to the various assumptions in the forecast, users can create several contingency plans that will apply under varying conditions of population growth, technological progress, and economic growth [21]. It is very useful in evaluating some possible future trends and consequences of all the policies. An electricity price modelling process allows policy makers to develop and simulate various energy and emissions scenarios. This flexibility is useful in comprehending the role of each policy instrument in relation to the economic energy systems in the future [22]. Users are able to simulate a range of potential future situations depending on the type and scope of the technology, policy and socio-economic factors. LEAP also benefits both conventional and power users since you can simply feed data into the system and perform complex modeling exercises [23].

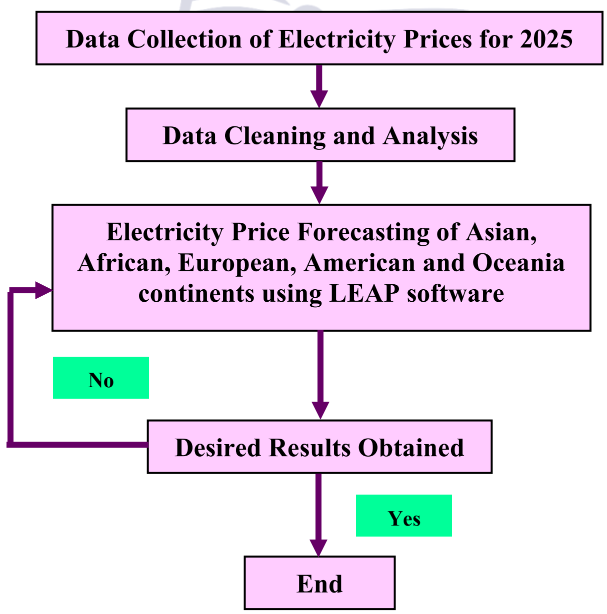

Figure 1: Research flow diagram of electricity price forecasting

End-user costs of electricity are highly dependent on country, region and consumption level and it is a lifetime cost per kWh of generated power taking into account renewable focus, cost of operation and maintenance, capacity factor, fuel cost and discount rates. The price of electricity can be determined by using the Eqn. (1) [24]. Cost of power generation employed in LEAP software of dispatchable (fossil) and intermittent (renewable) technology and it can be determined with the help of the Eqn. (2) [25]. Fuel expenses with escalation are a significant part of the variable cost in power generation which in most cases is the prevailing cost of electricity especially in thermal plants. Escalation is a measure of the effect of the costs on an annual basis as a result of inflation, market instability, geopolitical issues or supply chain interruptions. Escalation of fuel costs is unstable with fossil fuels and stable/zero with renewable fuels and could be outlined by using the Eqn. (3) [26]. A carbon cost add-on is an extra charge or economic variable included in the price, tariff or cost model which aims to recognize the environmental impact of carbon dioxide emissions. This is in conformity to forms of carbon pricing such as carbon tax schemes, cap-and-trade schemes, or emissions trading schemes, so that fossil fuel-based generation becomes less competitive than low-carbon generation such as solar, wind, or hybrids. LEAP penalty of fossil fuels and insignificant on renewables and can be estimated through the Eqn. (4) [27]. Demand and supply in electricity markets are equilibrated by electricity markets. In cases of high demand and low supply in peak hours, due to weather, prices are increased through price markup, a premium on the base cost to induce more supply, or to cover costs. The markup price in the demand supply can be determined using the Eqn. (5) [28].

$$Cost\ of\ Electricty\ (COE) = \frac{\mathrm{LT}_{t=0} \dfrac{RE + \text{O\&M cost}_t + \mathrm{FC}_t}{(1+r)^t}}{\mathrm{LT}_{t=0} \dfrac{CF\ \times 8760}{(1+r)^t}} \quad (1)$$

Where; LT is the lifetime, RE is the renewable emphasis, O&M is the operational and maintenance cost (fixed and variable), FC is the fuel cost, r is the discount rate, CF is the capacity factor, and 8760 is the number of hours in a year.

$$Power\ Generation\ Cost\ (PGC) = \mathrm{CC} \times \frac{r(1+r)^{LT}}{(1+r)^{LT} - 1} + \frac{OC_{fixed}}{8760\ \times CF} + \frac{OC_{variable} + FC}{8760\ \times CF} \quad (2)$$

Where; CC is the capital cost, r is the discount rate, LT is the lifetime, OC is the operational cost, FC is the fuel cost, and CF is the capacity factor.

$$Fuel\ Cost\ with\ Escalation\ (FCE) = FC_{voltaile}\ \times (1 + ESC)^t\ \times Inf^t \quad (3)$$

Where; FC is the volatile fuel cost, ESC is the escalation rate that is fuel specific, Inf is the inflation.

$$Carbon\ Cost\ Add\ on\ (CCA_t) = EF\ \times PC_t\ \times\ G_t \quad (4)$$

Where; EF is the emissions factor (tCO_2/MWh), PC is the carbon price ($\$/tCO_2$) and G is the generation.

$$Demand\ Supply\ Price\ Markup\ (P_{adj}) = P_t\ \times (1 + \frac{D_t - G_t}{IC \times 8760 \times CF}) \quad (5)$$

Where P is the fuel price, D is the demand in MWh, G is the generation in MWh, IC is the installed capacity (MW), and CF is the capacity factor.

III. Results and Discussion

Electricity cost has led to Singapore in Asia-Pacific at around 0.24 USD/kWh as of early 2025. Japan's unit cost of electricity at 0.20 USD/kWh and Hong Kong at 0.20 USD/kWh. Philippines unit cost of electricity at 0.15 USD/kWh and Thailand at 0.12 USD/kWh through gas and imports respectively. Malaysia has subsidized and lower rates of electricity about 0.05 USD/kWh, whereas Vietnam remains 0.08 USD/kWh courtesy of the hydropower development. Cambodia and Indonesia fall between 0.07-0.10 USD/kWh unit cost, having a tradeoff between coal consumption and electrification to the rural population. The national average cost of electricity in India is at 0.08-0.12 USD/kWh, depending on the state, it has been lower in coal-producing states such as Madhya Pradesh and has been higher in other regions such as Tamil Nadu. The state of Pakistan and Bangladesh is near 0.10-0.15 USD/kWh unit cost, being confronted by the fuel crisis and debts. Nepal and Bhutan exploit lower rates of less than 0.07 USD/kWh and thus they are helping the region. China uses coal dominance and state prices to enforcer low cost of electricity less than 0.10 USD/kWh, but industrial prices increase to 0.40-0.80 RMB/kWh regionally. The South Korea adapted to approximately 0.12 USD/kWh unit cost after 2023 increases during nuclear and import mixes. On the whole, the contradictions of subsidies in China and Indian markets are in opposition to the high market driven in Japan. The future forecast of electricity prices for the year 2030 of Asian continent is shown in Figure 2. Wind, solar, natural gas and furnace oil based electricity will have higher rates while hydro, biomass, geothermal, nuclear and coal will have lower rates of electricity in Asian continent in the year 2030.

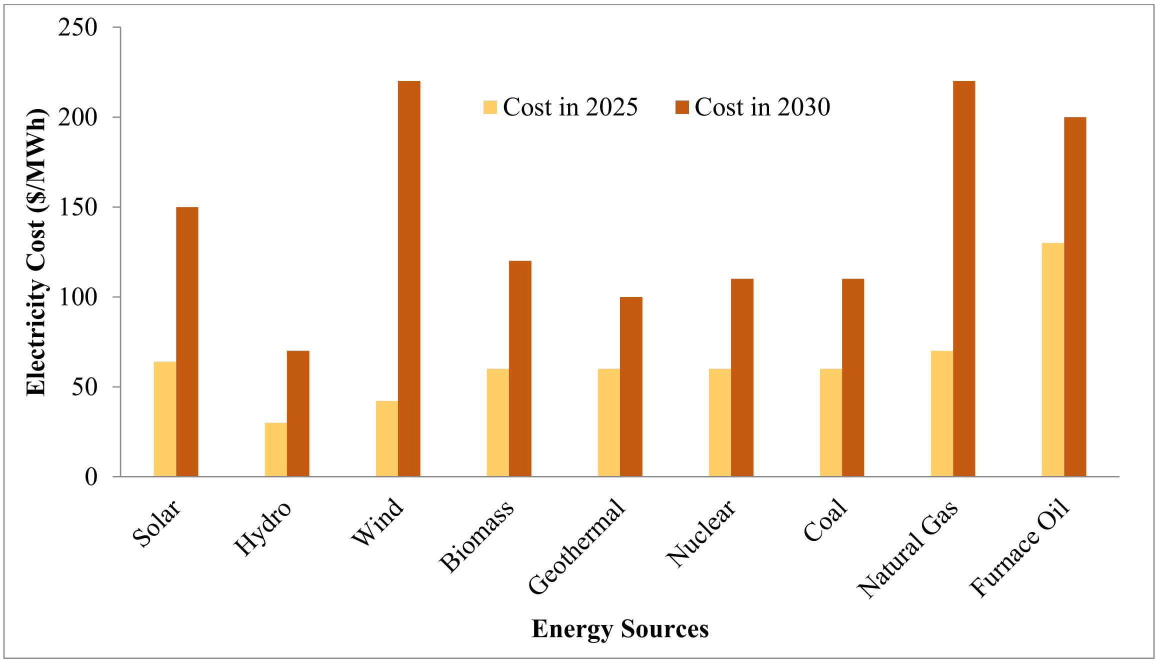

Figure 2: Electricity cost in Asian continent

Africa is widely different in electricity prices depending on the source of electricity, subsidies, dependence on imports, and infrastructure among others. As of mid-2024, Cabo Verde has the highest per unit electricity rates and is ranked top at 0.35 USD/kWh, then Kenya (0.26 USD/kWh) and Sierra Leone (0.25 USD/kWh). Other high-cost countries are Mali (0.23 USD/kWh) and Burkina Faso which is motivated by the reliance on fossil fuels. These are expensive electricity prices that burden families and companies in the economies that depend on imports. Hydropower subsidies mean that Ethiopia only charges 0.005 USD/kWh unit cost. Other countries with low scores (in most cases with oil/gas resources or state-sponsored) are Angola (0.015 USD/kWh), Zambia (0.023 USD/kWh) and Egypt (0.024 USD/kWh). In Libya and Sudan, the rates are comparable, at less than 0.01 USD/kWh, which is subsidized. The future forecast of electricity prices for the year 2030 of African continent is shown in Figure 3. Wind, solar, natural gas and furnace oil based electricity will have higher rates while hydro, biomass, geothermal, nuclear and coal will have lower rates of electricity in African continent in the year 2030.

The cost of electricity in Europe also differs widely as different countries have different household prices depending on the market forces and taxes of the energy markets, and the Eastern countries, in turn, have lower prices. Recent 2025 data with the Eurostat point out this gap and provide the rates per 100 Euro/kWh unit cost of electricity. Belgium tops it with a huge figure of 35.7 Euro/kWh then Denmark with 34.9 Euro/kWh close behind and Germany with over 30 Euro/kwh cost of electricity. Italy, Ireland and Czechia were above 30 Euro/kWh cost of electricity of it as well pushed by high network charges and renewable charges. The Eastern Europe region and applicants such as Turkey, Georgia, Kosovo, Bosnia and Herzegovina and Montenegro record less than 10 Euro/kWh. Such reduced rates are a result of subsidized energy and reduced reliance on imports. The future forecast of electricity prices for the year 2030 of European continent is shown in Figure 4. Natural gas and furnace oil based electricity will have higher rates while solar, wind, hydro, biomass, geothermal, nuclear and coal will have lower rates of electricity in European continent in the year 2030.

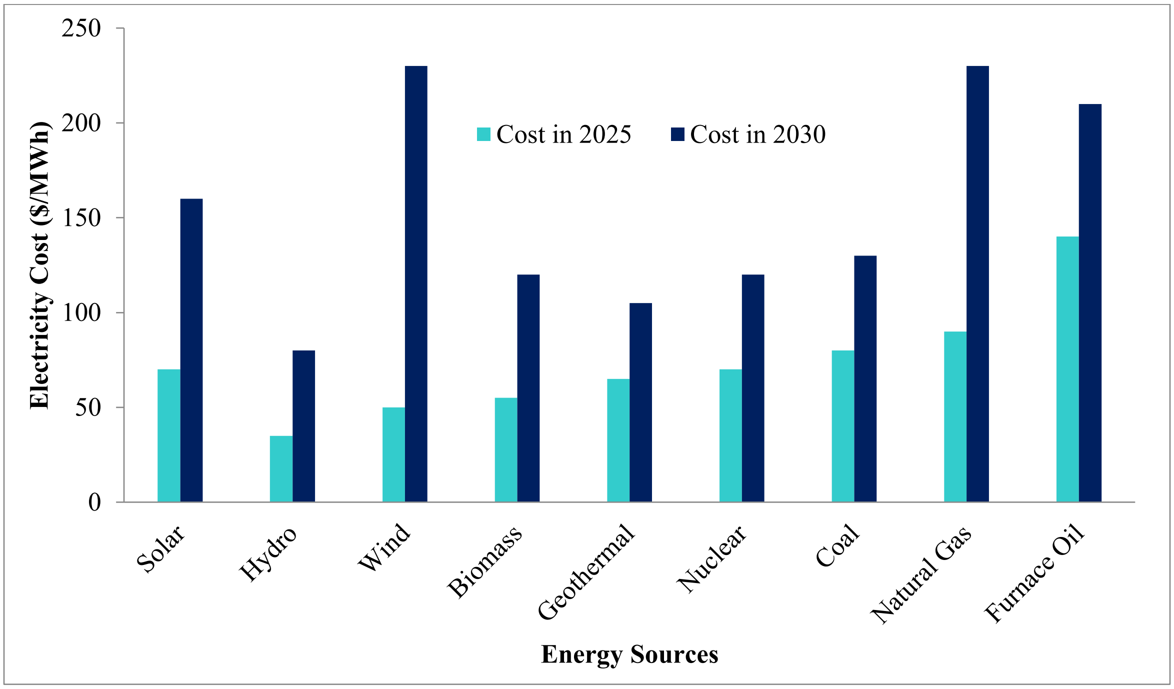

Figure 3: Electricity cost in African continent

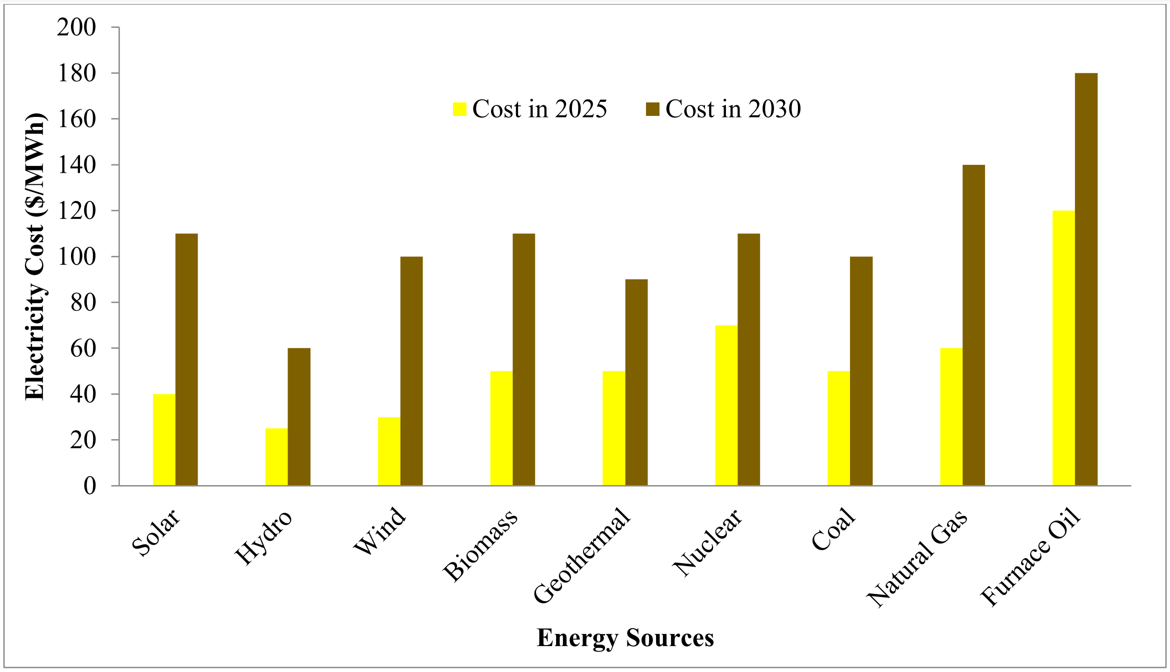

Figure 4: Electricity cost in European continent

The Electricity prices in the American continent are extremely different in various countries based on various factors such as sources of energy, subsidies and geographical factors. The countries in North America tend to possess moderate to high rates of electricity, whereas Latin American countries enjoy reduced subsidized rates. The statistics in late 2025 reveal that the United State will be averaging about 18 cents/kWh, and states such as Hawaii will be making above 39 cents/kWh. The United State average is 18.07 cents/kWh, with Nevada at 11.95 cents/kWh and Hawaii at 39.54 cents/kWh. The national rates in Canada are in the range of 0.10-0.15 USD/kWh, but in some provinces, such as Ontario, the current rates are approximately 0.13 USD/kWh. The average electricity prices in Mexico are 0.08-0.12 USD/kWh, and it is backed up by natural gas and renewable government subsidies. The highest cost of electricity is Guatemala at 0.30 USD/kWh as of 2023, then Uruguay and Jamaica at approximately 0.25 USD/kWh. Argentina is the lowest at less than 0.05 USD/kWh as it is highly subsidized whereas Brazil is similar to the United State at approximately 0.16 USD/kWh. Countries such as Chile and Colombia are between 0.15-0.20 USD/kWh, which is fuelled by a hydroelectric dependency. The future forecast of electricity prices for the year 2030 of American continent is shown in Figure 5. Natural gas and furnace oil based electricity will have higher rates while solar, wind, hydro, biomass, geothermal, nuclear and coal will have lower rates of electricity in American continent in the year 2030.

The prices of electricity in Oceania are much dependent on the energy source, infrastructure, and the degree of the dependence on imports. Moderate electricity rates of approximately 0.26-0.37 USD/kWh are applied to bigger countries such as Australia and New Zealand and other Pacific islands experience increased costs because they are dependent on diesel. In Australia, the electricity price is 0.262 USD/kWh and recently cost increases up to 10% in some regions as a result of the wholesale and network costs. The New Zealand is observed to have around 0.36 NZD/kWh which is backed by hydro and renewables and a bit higher than world average. Cost of electricity is also cheaper in Papua New Guinea at 0.33 NZD/kWh, though with unreliable supply and Fiji, 0.23-0.25 NZD/kWh with hydropower assistance. In Solomon Islands, 1.10 NZD/kWh, this is diesel-dependent and which is also of poor reliability, and in Vanuatu, 0.80 NZD/kWh because of the high costs of generation. Tonga and French Polynesia indicates the 0.40-0.50 NZD/kWh, which drifts towards the solar but is also expensive. The future forecast of electricity prices for the year 2030 of Oceania continent is shown in Figure 6. Solar, wind, natural gas and furnace oil based electricity will have higher rates while hydro, biomass, geothermal, nuclear and coal will have lower rates of electricity in Oceania continent in the year 2030.

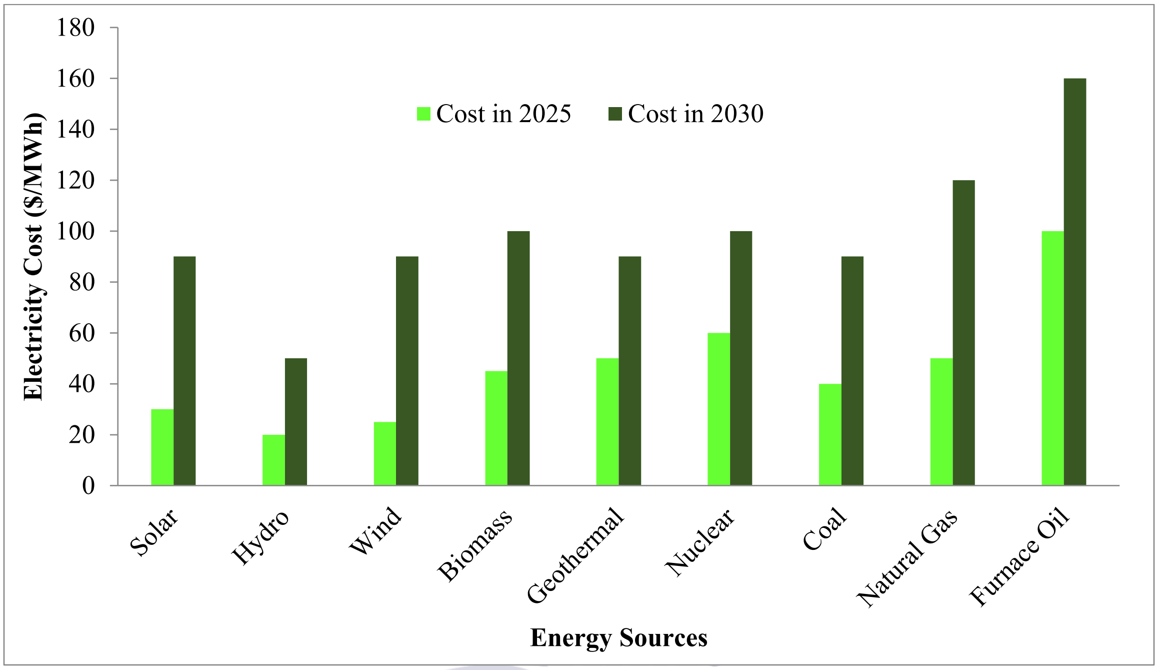

Figure 5: Electricity cost in American continent

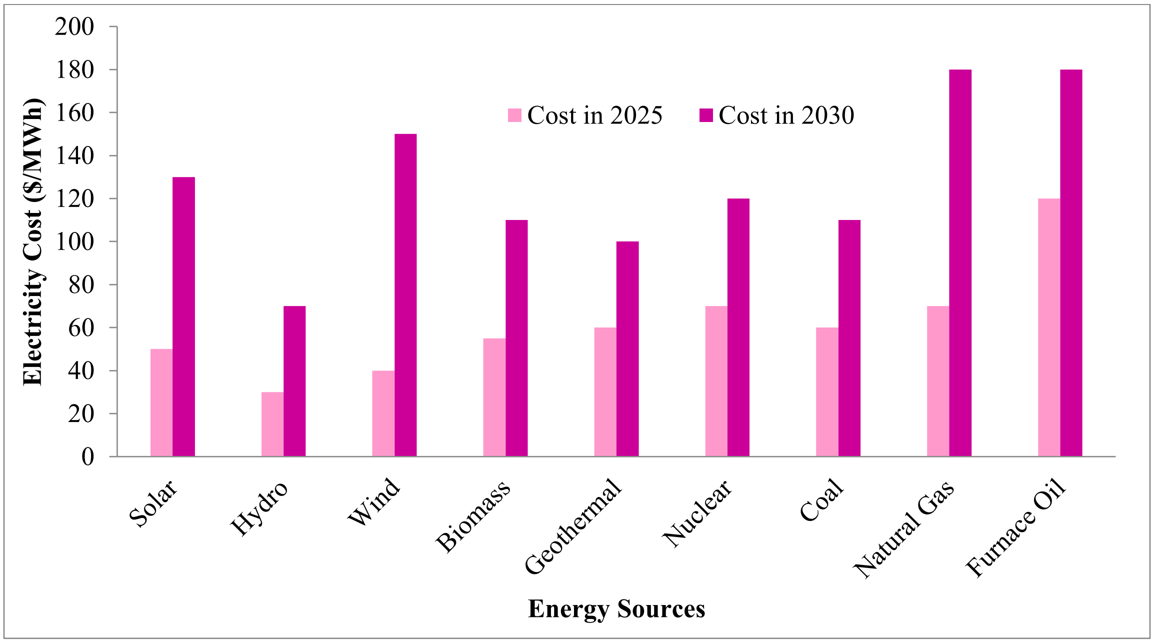

Figure 6: Electricity cost in Oceania continent

VII. Conclusion

Electricity price forecasting is very important for the sustainable electricity markets. Numerous energy sources are exists around the globe that helps to supply power for economic development. This study has forecasted the electricity prices in each continent of the world and suggests the greater reliance on green energy sources for sustainable environment. It is concluded that African continent is very poor, even though they hardly manage the food for survival then how they manage the electricity generation and costing aspects for better life. African region is highly dependent on fossil fuels and they have very less renewable based power generation due to the lower economic sources. In Asian continent, some developed countries are growing at a faster face in green energy sector however, some less developed countries have also made clean energy polices for economic growth. Cost of green electricity is much lower than other regions due to the greater development solar, wind, and hydro technologies. European and American continents are well established and they have all economic resources to manage electricity prices at a reasonable cost. Australia and New Zealand are also well developed in Oceania continents and rest of the areas in this continent is highly dependent on the diesel based power generation.

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