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RELATIONSHIP BETWEEN OIL AND RENEWABLE ENERGIES PRICES

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ABSTRACT
Large companies in the oil sector have been expanding their activities to the renewable energy segment. The objective of this work is to identify patterns and relationships - in the 10 last years - between oil price and prices of the following renewable energies: wind, hydroelectric, solar, and bioenergy. The analysis of standards and the identification of relationships help decision-makers to define strategies and increase operation efficiency. Besides, it contributes to the development of models capable of predicting, interpreting, and testing hypotheses about the data. The main analytical and data treatment methodology used in this work comprises statistical tests involving Cross-Correlation and Granger Causality. The Cross-Correlation Test showed a strong negative correlation between oil and wind energy prices, and the Granger's test did not show causality between them. New studies comparing oil and renewable energy prices by country and covering a longer period can bring interesting results.

KEYWORDS
oil price; renewable energy price; Cross-correlation test; Granger's Causality test

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1. INTRODUCTION

Oil is the energy source most used around the world nowadays, and it has a strong economic impact in the economy of producing countries like Brazil. From crude oil, it is possible to obtain many products such as gas, naphtha, gasoline, kerosene, and diesel. These products are used as final goods or as inputs for other productive chains such as chemical and petrochemical.

Despite its economic importance, the use of oil has been questioned due to reasons such as: (1) it is a non-renewable energy source (2) the depletion of more accessible reserves is displacing the exploratory frontier to deep seas, (3) the processes of exploring, producing, and utilizing oil lead to pollution and other negative environmental impacts. In this context, it is of utmost importance that researchers explore alternative energy sources capable of reduce the demand for oil.

In 2018, the World Bank stopped financing the oil business to focus on renewable energies **(Romanzoti, 2017)**. These energies come from natural resources such as wind, rain, sun, bioenergy, tides. Besides being inexhaustible, they cause less pollution and are not the reason behind political conflicts within and outside countries. On the other hand, they depend on geographic location as well as factors such as climate and seasonality.

Many companies in the oil sector - such as Petrobras, ExxonMobil, BP, and Equinor - are investing in the renewable energy market **(Portal Solar, 2018)**. Thus, resources from oil exploration and production must finance, at least in part, the global transition to new energies. Oil price, however, is volatile because it depends on geopolitical and economic factors, such as supply and demand in the world market.

The objective of this work is to identify patterns and relationships between the oil price and the prices of the following renewable energies: wind, hydroelectric, solar, and bioenergy in the past decade. The identification of the patterns and relationships helps decision-makers to define their strategies and operate more efficiently. Besides, it contributes to the development of models capable of predicting, interpreting, and testing hypotheses about the data.

There are few studies about this topic. **Henriques and Sadorsky (2008)** showed how the stock price of the alternative energy companies is affected by the variations in the oil price. The authors developed four vector autoregression models to investigate the empirical relationship between alternative energy stock prices, technology stock prices, oil prices, and interest rates. The results show that stock prices of the companies are affected by oil prices variation. **Kyristsis and Apostolos (2017)** also investigated the effects of oil price variation on the stock returns of clean energy companies, finding different results. Using a bivariate structural vector autoregression model and monthly data (May 1983 to December 2016), the authors showed that the uncertainty of the oil price did not have a statistically significant effect on stock returns and that the relationship between them is symmetric. Finally, **Deniz (2019)** investigated the impact of oil price on renewable energy considering the distinction between oil exporters and importers. This study examines the relationship between oil price volatility and renewable energy for oil exporters and importers using different methodologies. The results reflect distinct results for oil exporters and oil importers due to their diverse motivations.

The present study begins with a brief explanation of each energy source, followed by the presentation of data organized and summarized in graphs, and the discussion of results of Cross-Correlation and Granger Causality tests. The Cross-Correlation test indicates whether the variables are associated (strength and direction) and Granger's Causality test if the inclusion of past data from one variable improves the future forecast of the other variable.

2. OIL PRICE

Oil is a commodity, and its price is determined by worldwide supply and demand. Supply increases or demand decreases cause a reduction in oil price while supply decreases or demand increases lead to the opposite effect.

Table 1 shows the average annual price - from 2000 to 2019 - of WTI and Brent oils **(Macrotrends, 2020)**. Figure 1 shows the similarity between the behavior of the two series. Therefore, the choice of one of them does not affect the results of the study.

Table 1. Oil average annual price. Source: **Macrotrends (2020)**.

Year	Brent (US$/barrel)	WTI (US$/barrel)
2000	30.38	29.74
2001	25.98	25.23
2002	26.19	26.56
2003	31.08	30.83
2004	41.51	41.59
2005	56.64	57.28
2006	66.05	66.96
2007	72.34	74.94
2008	99.67	98.58
2009	61.95	63.92
2010	79.48	79.98
2011	94.88	97.00
2012	94.05	94.25
2013	97.98	97.60
2014	93.17	91.22
2015	48.66	49.30
2016	43.29	44.46
2017	50.80	51.86
2018	65.23	64.54
2019	56.99	57.09

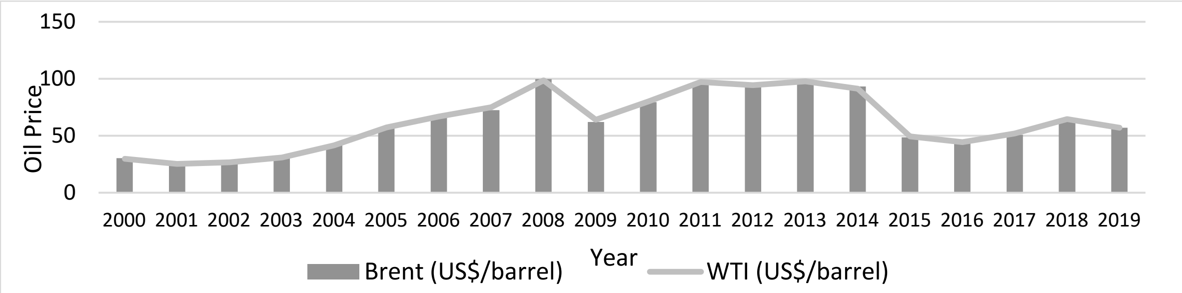

Figure 1. WTI and BRENT oil price (US$/barrel).

Various factors can affect the supply and demand for oil and, consequently, its price, among them are global crises, discovery of new reserves, emergence of alternative energy sources, and geopolitical tensions. Global crises, such as that caused by the coronavirus, tend to decrease countries' economic activities, therefore, reducing oil demand. The discovery of new reserves, on the other hand, contributes to expand the oil supply in the market **(Amadeo, 2019; Copelovitch et al., 2016; Morgan, 2009)**.

Globally, the main producers of oil are Russia, followed by Saudi Arabia, the United States, China, and Brazil. Saudi Arabia, together with other producing countries, participates of the Organization of Petroleum Exporting Countries (OPEC). The OPEC has a strong influence on the oil price because it controls the quantity of oil supplied. These member-countries generate more than 30% of world production and hold more than 80% of global reserves. The largest importers are the European Union, China, the United States, India, and Japan. In 2010, Brazil – historically an importer of oil – has discovered important offshore reserves and started to occupy an important position in the market **(IEA, 2018)**.

3. RENEWABLE ENERGY

Renewable energies come from inexhaustible natural resources such as the sun and wind. Although they are called "clean" energy, they are not completely clean because require equipment, materials, and facilities that negatively affect the environment **(IEA, 2018)**.

Table 2. Average annual prices of renewable energies (US$/kWh). Source: **IRENA (2020a)**.

Year	Wind	Hydro	Solar	Bioenergy
2010	0.084	0.041	0.370	0.074
2011	0.080	0.040	0.287	0.054
2012	0.077	0.042	0.221	0.059
2013	0.080	0.045	0.175	0.080
2014	0.075	0.037	0.165	0.080
2015	0.067	0.041	0.133	0.073
2016	0.065	0.053	0.119	0.071
2017	0.064	0.055	0.097	0.071
2018	0.055	0.048	0.085	0.061
2019	0.139	-	-	-

The prices of alternative energies were obtained from the International Renewable Energy Agency site (IRENA). IRENA is an intergovernmental organization founded in 2011 with the goal of promoting a wide and sustainable adoption of renewable energy. Since 2012, it collects and reports performance and price data for these energies **(IRENA, 2020a)**.

To calculate the price (or the *Global Weighted Average Cost of Electricity* (LCOE)), IRENA uses Equation 1 and data from various sources around the world.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (1)$$

LCOE is Global Weighted Average Cost of Electricity; I_t is the investment per year t; M_t is the operations and maintenance cost per year t; F_t is the fuel cost per year t; E_t is the energy generated per year t; r is the discount rate (*Weighted Average Cost of Capital* or WACC) and n is the lifetime of the installation **(IRENA, 2020)**.

Table 2 shows the prices of renewable energies. To facilitate the comparison, values were deflated (base year US $ 2019) and discounted according to the average cost of capital. For OECD countries and China it considered the real cost of capital of 7.5% per year and, for the rest of the world, 10%. Figure 2 compares the behavior of prices over time.

The price of solar energy is higher than the others alternative sources. However, this difference has been decreasing over the years and, currently, energy prices tend to present close levels. Following, this work will provide a brief presentation of the energies under analysis: wind, hydroelectric, solar, and bioenergy.

3.1 Wind energy

Wind energy produces electricity through wind. The wind causes the rotation of turbine blades and transforms kinetic energy into rotational. The turbines, in turn, are connected to a generator that transforms rotational energy in electricity **(IRENA, 2020b)**.

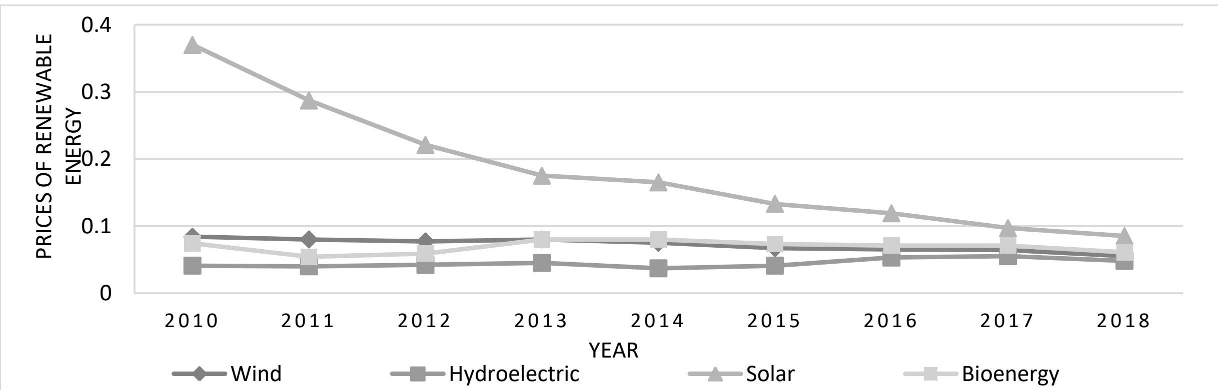

Figure 2. Price of renewable energies (US$/KWh). Source: **IRENA (2000a)**.

Figure 3. Oil price *vs*. price of wind energy. Source: **IRENA (2020a)**.

The price of energy from wind farms is determined by total installed cost; capacity factor (ratio between actual production and total capacity over a period); Operation and Maintenance (O&M) cost; life cycle of the project; and capital cost. Some components have greater weight in the price composition, as the turbines for example, but operating and maintenance costs (O & M) is also an important part of the energy price (about 30%) **(IRENA, 2020)**.

Wind energy production is profitable only in open and windy areas. Otherwise, the energy produced is not enough to cover the high initial investments. For this reason, a growing number of plants are installed on the high sea where the winds are intense and constant. Offshore wind farms are operated in a distant and highly corrosive environment. Because of that, they require greater investments and have higher operating and maintenance costs **(IRENA, 2020b)**.

Over the years, markets experienced a reduction in the average global price of wind energy. In 2019, the price of onshore energy dropped 39% compared to 2010 (from the US $ 0.086 to US $ 0.053 / kWh) and, in the case of offshore, 29% (from US $ 0.161 to US $ 0.115 / kWh). Projections indicate that the price could be below $ 0.05 / kWh in 2023 **(IRENA, 2020a)**.

The reduction in prices is due to several factors: lower turbine prices, greater competition and experience from operators and service providers, new technologies, standardization of parts and equipment, and economies of scale.

Figure 3 shows the normalized prices of oil and wind energy. Initially, it is not possible to identify an association between these two variables. The price of wind energy shows a downward trend over time, without seasonality.

3.2 Hydroelectric energy

Historically, hydropower is the cheapest form of energy in many countries. The hydroelectric plants produce electricity through the flow of water that turns turbine blades. Some hydroelectric plants have a dam and reservoir. Thus, they maintain a water supply and can meet its demand when necessary. Those that do not have dams have a smaller production scale but are considered more environmentally friendly because they do not affect the flow of the river **(IRENA, 2020c)**.

Hydroelectric plants are capital intensive and have a long maturation time. They involve planning activities; project development; authorization by public agents; construction, operation, maintenance of large and complex installations. The initial investment varies according to location, local conditions, capacity, and performance, which can be quite different.

Data collected by IRENA showed that the price in 2019 was 6% higher than in 2018, and 27% higher than in 2010 (US $ 0.037 to US$ 0.047/kWh). The increase was due to rising installation costs, especially in Asia, which was responsible for implementing many projects in adverse conditions. Despite the price increase over time, 89% of the capacity added in 2019 produce energy at a price lower than the cheapest fossil source **(IRENA, 2020a)**.

Figure 4 shows the normalized prices of oil and hydroelectric energy. Until 2014, the price of

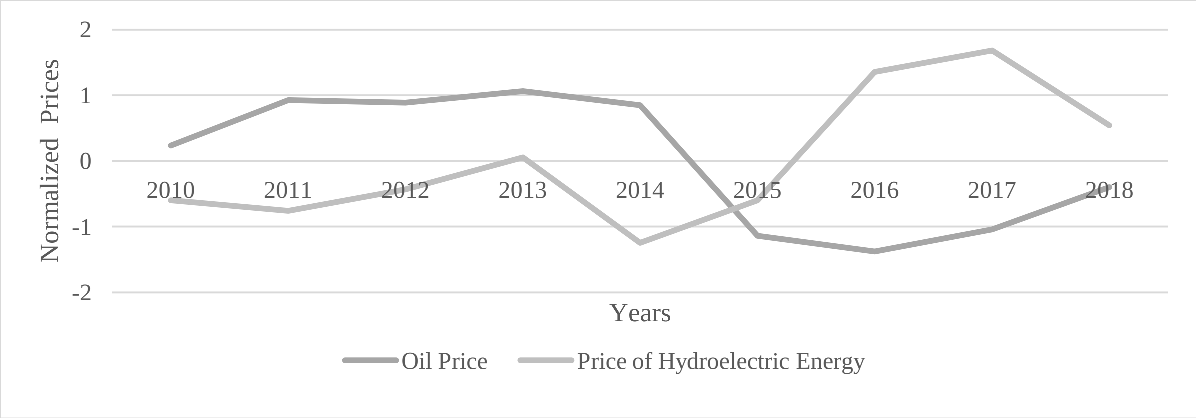

Figure 4. Oil price *vs*. price of hydroelectric energy. Source: **IRENA (2020a)**.

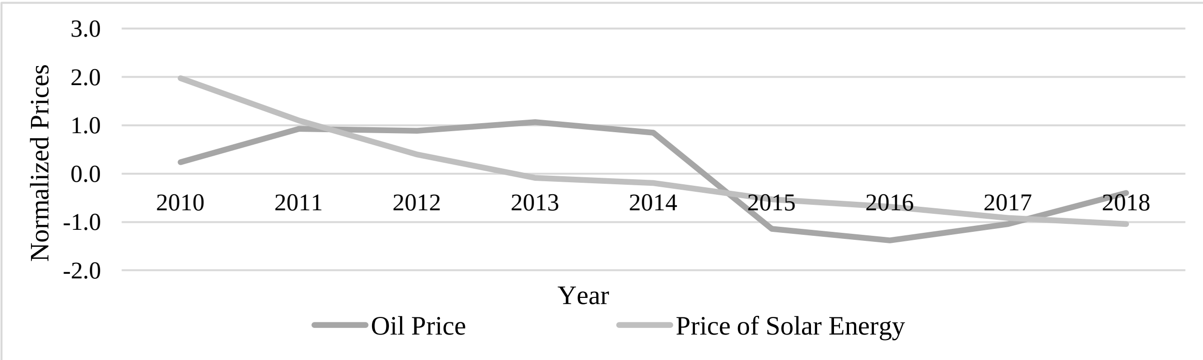

Figure 5. Oil price *vs*. price of solar energy. Source: **IRENA (2020a)**.

hydroelectric plants remained relatively stable. After that, it showed an increase and since then it has remained at high levels.

3.3 Solar energy

Solar energy is used worldwide, and it can be generated in two ways: by photovoltaic solar cells (PV) or by concentrated solar power (CSP) **(IRENA, 2020d)**.

- Photovoltaic cells are electronic devices that convert sunlight in electricity. Examples are panels installed on calculators or in buildings. Photovoltaics can be used both on a commercial scale and in homes.

- Concentrated solar energy, also known as solar thermal energy, uses mirrors to concentrate the sun's rays and generate energy. These rays heat a fluid until its evaporation, and the steam turns the turbine to generate electricity. Concentrated solar energy can only be used on a large scale because it requires the installation of power plants.

The average price of solar energy - both photovoltaic and concentrated - has been decreasing over the years. This is due to the processes optimization and efficiency gains associated with technological evolution: between 2010 and 2019 the price of photovoltaic energy decreased by 82% (from the US $ 0.378 / kWh to $ 0.068 / kWh), and the concentrated by 47% ($ 0.346 / kWh to $ 0.182 / kWh) **(IRENA, 2020a)**.

However, there is a wide variation in the price of solar energy from country to country: in 2019, the price in India was US$ 618 / kWh and, in Russia was $ 2,117 / kWh, for example. The differences in cost are essential to understand the logic of each market and identify opportunities for improvement. It is expected that, with time and the maturation of the markets, the difference observed in prices decline.

Figure 5 shows the normalized prices of oil and solar energy. The price of solar energy has a downward trend throughout the period, without the presence of seasonality.

3.4 Bioenergy

Bioenergy is the energy obtained through biomass and it has two categories: traditional and modern. The traditional one refers to energy obtained from the combustion of wood, animal waste, and charcoal. The modern, diversely, refers to energy obtained from the bagasse of plants. To analyze this energy, it is necessary to consider three factors: type and availability of raw material, conversion process, and technology used for energy generation **(IRENA, 2020e)**.

Bioenergy has big potential in countries with a large population, such as Brazil, India, and China. In 2017, Brazil was the second-largest consumer in the world of this type of energy, behind only the United States **(IEA, 2018)**. Besides, Brazil is a leader in liquid biofuels and has the largest fleet of flexible vehicles that can use both bioethanol and gasoline **(IRENA, 2020)**.

Between 2010 and 2019, the average price of bioenergy declined 13% (from \$ 0.076 / kWh to \$ 0.066 / kWh). Figure 6 shows the normalized prices of oil and bioenergy. The price increase between 2011 and 2013; since then, it has been declining. It is not possible to notice the presence of seasonality in the series **(IRENA, 2020a)**.

4. TIME SERIES AND STATISTICAL TESTS

Many statistical tests for estimating, predicting, and inferring time series require, to be valid, that the series be stationary. A series is stationary when its mean and variance are finite and constant and the covariance between two periods is a function of the size of the gap and not of the time **(Gujarati & Porter, 2011)**.

Because time series are rarely stationary, to apply the tests it is necessary to transform the series into stationary ones. This can be done through the first difference or, when necessary, considering a longer time lag **(Carneiro, 1997)**.

The Granger test is valid only for stationary series. Therefore, the Dickey-Fuller (DF) test was used to check series stationarity. When necessary, we applied differences until obtaining the stationarity **(Gujarati & Porter, 2011)**.

4.1 Cross-Correlation test

The Cross-Correlation test is a measure of association (force and direction) that allows comparing and identifying the existence of a relationship between two-time series at different times. A variable can be related to past values of the other series, so it is necessary to calculate the correlation with different time lags **(Gujarati & Porter, 2011)**.

The cross-correlation coefficient is given by Equation 2:

$$r_{xy}(\tau) = \frac{\sum_{t=1}^{n-|\tau|} x_t \, y_{t+\tau}}{\sqrt{\sum_{t=1}^{n} x_t^2 \, \sum_{t=1}^{n} y_t^2}} \qquad (2)$$

Where x_t and y_t are the variables analyzed in time t, and τ is the lag time considered. The correlation coefficient $r_{xy}(\tau)$ varies from -1 to 1. A greater correlation in absolute terms indicates a stronger association. If r_{xy} = -1, the correlation is

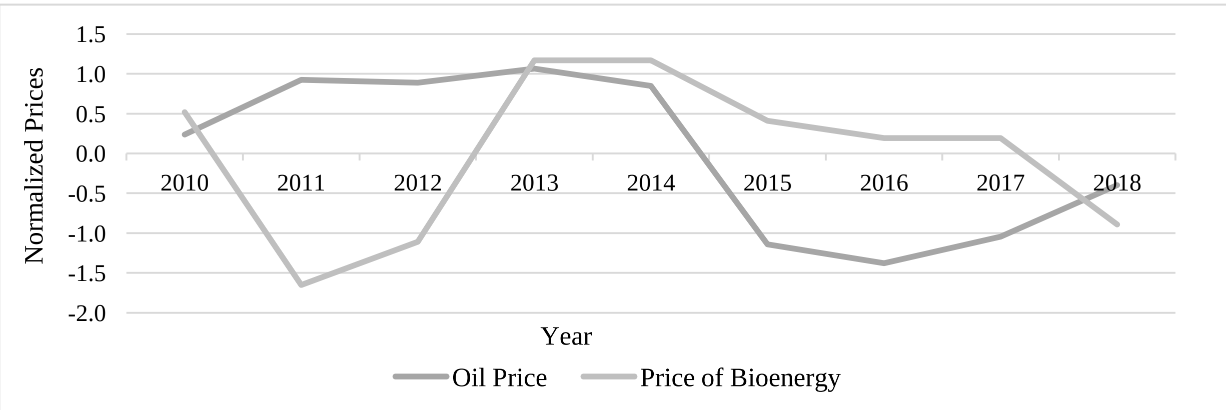

Figure 6. Oil price *vs*. price of bioenergy. Source: **IRENA (2020a)**.

negative perfect; if r_{xy} = 1, is positive perfect; and, finally, if $r_{xy} = 0$, there is no correlation. We can also calculate the coefficient of determination ${r_{xy}}^2$ which indicates how much of the y variation can be explained by the x variations.

To apply the test is necessary to **(Enders, 2015)**:

1. Calculate the correlation between the series using different time lags,
2. Identify the time lag that has the highest correlation in absolute terms.

4.2 Dickey-Fuller test (DF)

The Dickey-Fuller (DF) test identifies if the series is non-stationary (null hypothesis), that is, the series has a unit root. Thus, for the series to be considered stationary, the null hypothesis must be rejected.

To apply the test is necessary to **(Enders, 2015)**:

1. Estimate Equation 3 using the least-squares method.

$$\Delta Y_t = \delta Y_{t-1} + u_t \qquad (3)$$

2. Divide the estimated coefficients of the Y_{t-1} by the standard error to calculate tau (T) and compare it with critical tau of the Dickey-Fuller table.
3. If the absolute value of the statistic T exceeds the critical value, there's a fail in reject the null hypothesis, and the series is considered non-stationary. Otherwise, if T is smaller than the critical T, we can consider the series stationary.

4.3 Granger's Causality test

The test states that x is Granger's cause of y if including x_{t-j} (x past value) improves the prediction of y_t. The test is performed in both directions, that is, x causing y and y causing x **(IRENA, 2020c and 2020d)**.

In mathematical terms, the test estimates the regressions of Equations 4 and 5 that indicate that x (or y) values are related to x and y past values plus an error.

$$X_t = \sum_{j=1}^{m} a_j X_{t-j} + \sum_{j=1}^{m} b_j Y_{t-j} + u_{1t} \qquad (4)$$

$$Y_t = \sum_{j=1}^{m} c_j X_{t-j} + \sum_{j=1}^{m} d_j Y_{t-j} + u_{2t} \qquad (5)$$

In the Granger test, the null hypothesis states that there is no causality between x and y. Therefore, x does not contribute to the predict y and vice versa. After estimating regressions, four situations can occur: y lagged values improve x forecast, x lagged values improve y forecast, both x and y contribute to the forecasts, and, finally, there is no causality, and the variables are independent **(Carneiro, 1997; Gujarati & Porter, 2011)**.

5. METHODOLOGY

Figure 7 shows the steps developed in the work.

Initially, we surveyed the average annual prices of WTI oil and renewable energies. The ideal would have been to use a larger volume of data - monthly, quarterly, or even extend the period considered - to improve the accuracy of statistical tests, but these data were not found.

The data available were summarized in graphics. The graphics allow identifying seasonality, long-term trends, and the occurrence of unexpected events, contributing to short-term diagnostics and predictions. However, seeking

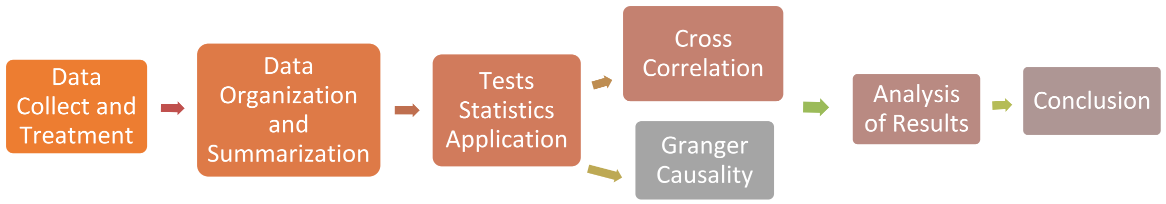

Figure 7. Work stages.

Table 3. Criteria of the correlation. Source: **Mukaka (2012)**.

r Range	Correlation type
-1 to -0.9	Very strong negative correlation
-0.89 to -0.7	Strong negative correlation
-0.69 to -0.4	Moderate negative correlation
-0.39 to -0.2	Weak negative correlation
-0.19 to -0.01	Very weak negative correlation
0	Without correlation
0.01 to 0.19	Very weak positive correlation
0.2 to 0.39	Weak positive correlation
0.4 to 0.69	Moderate positive correlation
0.7 to 0.89	Strong positive correlation
0.9 to 1	Very strong positive correlation

Table 4. Correlation between oil price and price of renewable energies.

Lags	0	1	2	3	4	5	6	7	8	9	10
Wind	-0.52	-0.53	-0.60	-0.75	-0.92	-0.87	-0.82	-0.85	-0.84	-0.79	**-0.96**
Hydro	-0.67	**-0.88**	-0.54	-0.50	0.76	0.76	-0.19	-	-	-	**-**
Solar	0.56	0.58	0.57	0.39	-0.78	-0.82	**-0.92**	-	-	-	-
Bioenergy	-0.09	0.22	0.58	0.63	-0.60	**-0.65**	-0.45	-	-	-	-

patterns and relationships through graphic representation can be subjective. The most accurate way to identify patterns and relationships between two variables is through statistical tests.

Cross-Correlation and Granger's Causality tests were developed using the free software Real Statistics, an add-in that extends Excel's statistics capabilities. The tests considered the largest time lags possible and a significance level (α) of 5%. The significance level is the probability of rejecting the null hypothesis when it is true.

1. Cross-correlation test was applied to verify the existence of an association between variables. In this work, to indicate the strength and direction of the correlation, the Mukaka criteria was adopted **(Mukaka, 2012)** (Table 3).

2. Dickey-Fuller test was applied to verify if the series is stationary. If not, the difference was made until achieving the stationarity.

3. Granger's Causality Test was applied in both directions, that is, variations in the oil price is Granger's cause of the variations in the prices of renewable energies, and prices of renewable energies are Granger's cause of the variations in oil price. The results of the work are as follows.

6. RESULTS

6.1 Cross-Correlation test

Table 4 shows the results of the correlation between oil and renewable energies prices and highlights the one with the highest intensity in module.

The cross-correlation between oil and wind energy prices is negative throughout the period studied, being moderate for lags 0 and 1, and either strong and very strong in other periods. Thus, it indicates the existence of an inverse association that intensifies over time. When the price of oil increases, wind energy decreases, and vice versa. The coefficient of determination at lag 0 indicates that 27% of the variation in the price of wind energy can be explained by the variation in the price of oil. In the correlation at lag 10, the coefficient of determination indicates that 92% of the variation in the price of wind energy can be explained by the variation in the price of oil.

Between oil and hydroelectric energy prices, the correlation is moderate negative in the first 4 lags, it becomes strong positive in lags 4 and 5, and, finally, it is very weak negative in lag 6. The inversion from negative to positive indicates that there was a structural break. Structural breaks are

Table 5. Dickey-Fuller test.

t-critical: -1.96	First Difference	
	T-Stat	Results
Oil	-4.35	Yes
Wind	-3.35	Yes
Solar	-2.57	Yes
Hydroelectric	-2.18	Yes
Bioenergy	-2.92	Yes

Table 6. Granger's Causality test.

	Valor-p							
Lags	Oil-->Wind	Win-->Oil	Oil-->Solar	Solar-->Oil	Oil-->Hydro	Hydro-->Oil	Oil-->Bio	Bio-->Oil
1	0.79	0.36	0.60	0.62	0.08	0.06	0.83	0.93
2	0.93	0.64	0.94	0.14	0.72	0.05	0.84	0.55
3	0.93	0.26	-	-	-	-	-	-
4	0.88	0.59	-	-	-	-	-	-
5	0.97	0.67	-	-	-	-	-	-

changes in the dispersion and/or slope of the series **(Gujarati & Porter, 2011)**. These changes can be abrupt or gradual and, in general, result from external shocks or changes in specific country's economic policies.

The price of hydropower energy, which remained relatively stable ~~up~~ until 2014, suffers inflection. The **IRENA (2020c)** points out as the main cause of price increase, the additional expenses related to the cost of projects. This occurred in Asia, which faced factors such as distance and adverse conditions for the hydroelectric plant's installation.

The correlation between oil prices and solar energy is moderate positive in the 0 to 3 lags, and, in the others, strong negative. It is possible to observe in Figure 5 that the structural break is associated to oil price, since the price of solar energy showed a downward trend in that period.

Finally, the correlation between oil and bioenergy prices is moderately positive for lags 2 and 3, and moderate negative thereafter. This structural break occurred because between 2011 and 2013 there was an increase in the price of bioenergy. Since 2014, the price has declined but remains at high levels.

6.2 Dickey-Fuller (DF) test

The Dickey-Fuller (DF) test indicates whether the series is stationary or not. As already mentioned, time series rarely have stationary behavior. This can be solved by calculating the first difference or even larger lags, if necessary. Table 5 summarizes the results obtained by making the first difference (critical t is -1.96 for the significance level of 5%).

After the first difference, all series showed a stationary behavior. Thus, making it possible for us to perform Granger's causality test.

6.3 Granger's Causality test

Granger's test shows whether past values of oil price contribute to estimate renewable energy prices and vice versa. The price series of the renewable energy used in this study are obtained annually, and three of them cover only the last ten years. Due the small number of data available, it was not possible to carry out the test for the ten lags as initially proposed. The calculation was performed for as many lags as possible. Table 6 summarizes the results.

To reject the null hypothesis and conclude by the causality, the probability-value (p-value) must be less than 5% (statistical significance). Table 6 shows that oil prices cannot be considered a cause (in the Granger sense) of wind, solar, and bioenergy prices. On a different note, the prices of these three energies do not cause the oil price.

For hydropower, p-value is close to the rejection area in three situations: oil price causes the price of hydropower in lag 1 (p = 0.08), and the price of hydroelectric energy causes the oil price in lags 1 and 2 (p = 0.06 and p = 0.05). This may be because hydroelectric is the second most used source of energy in the world and, for this reason, it is affected by oil price variations.

7. CONCLUSION

The objective of the work is to identify patterns and relationships, through statistical tests, between the oil price and prices of four renewable energies. This work uses Cross-correlation, Dickey-Fuller, and Granger causality tests to obtain the results presented.

The identification of patterns and relationships between oil prices and renewable energy prices contributes to the development of models capable of predicting, interpreting, and testing hypotheses about the data because they indicate the variables that contribute to a better estimate of the equation's differentials used. Solar and wind energy showed a downward trend and the absence of seasonality throughout the period, while hydroelectric and bioenergy showed relative price stability, and then, a rise and a gradual decline.

The cross-correlation test showed a structural break in the hydroelectric energy and bioenergy series. The occurrence of structural breaks can skew the results and, consequently, compromise the analysis. Thus, it is important understand its real causes and impacts. In this sense, new studies using a larger volume of data are recommended. Finally, Granger's test did not show causality between oil and prices of renewable energy.

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