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Article

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An Analysis of Electricity Generation with Renewable Resources in Germany

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ABSTRACT

Germany has an experience of renewable energy policies that encourages their usage, achieving technological migration and the redesign of its power generation matrix, achieving 112 GW of renewable resources at 2017. The research presents an analysis between the energy policies and the electricity statistics, the results forecast a date in which they will reach the goal of 50% of annual generation of total electric power by renewable sources, a goal set in 2012.

Keywords: Energy Policy, Renewable Energy, Forecasting, Energiewende
JEL Classifications: K29, Q48

1. INTRODUCTION

Energy security plays a vital role in the countries's development agenda, due to the increase in energy demand (Grimaldo et al., 2017) and the volatility of hydrocarbon prices (Regnier, 2007); technological changes have gradually allowed the migration of the usage of fuels to electrical energy (BP, 2018), which may come from renewable sources. Generation by Conventional Energy Sources (CES) is predominant in all Net Installed Electricity Generation Capacity (NIEGC) (Afonso et al., 2017). Environmental protocols promote the reduction of CO_2 production, through the migration of generation with CES by generation Non-Conventional Renewable Energy Sources (NCRES) (Ochoa et al., 2019; Milanés et al., 2020). Germany is one of the countries that has invested to achieve a sustainable energy transition, with a high participation of NCRES technologies (Pescia and Graichen, 2015; Quitzow et al., 2016).

Germany uses a program called Energiewende, which contemplates and promotes the objectives of combating climate change, improving energy security, guaranteeing competitiveness, stimulating growth towards a sustainable and environmentally friendly energy system, and promoting the gradual dismantling of nuclear facilities to avoid the risks of generation with this type of source (Morris and Pehnt, 2012; Pescia and Graichen, 2015). The Erneuerbare-Energien-Gesetz (EEG) law, known in English as "Renewable Energy Sources Act" (RES Act), evolved to integrate and be sufficient for the demands of the energy sector regarding to NCRES, however the energy transition has become more unsustainable economically in recent years (Thalman and Wehrmann, 2018) and everything points to the fact that the law must follow its pace of evolution to keep the renewable energy sector in a competitive environment (Bruns et al., 2011; Bohringer et al., 2017; Andor et al., 2017; Leiren and Reimer, 2018).

RES Act 2012 established objectives for national electricity consumption, by 2030 the goal was set to have 50% consumption with NCRES. The legal and regulatory framework related to NCRES in Germany was studied to analyze the growth of installed capacity and generation through NCRES in relation to RES Acts. The research will evaluate the evolution of electricity consumption by CES and NCRES to forecast the date in which Germany will achieve the goal of 50% set for 2030, this will determine the effectiveness of the legal framework used to incentivize NCRES projects (Kreuz and Müsgens, 2018).

2. MATERIALS AND METHODS

A comparison was made between electricity generation with CES and NCRES in Germany to forecast the date in which it is expected to reach the goal of 50% of total electric power generation through NCRES established by the RES Act (2012). The growth of the installed capacity and the generation of renewable electric power was analyzed to evaluate the increase of these variables due to the changes in the regulation, the years of the RES Acts will determine the periods of time; The RES Act is considered from the year 2000 up to date due to the higher growth rates.

Two models were designed to establish the percentage behavior of electricity generation by CES and NCRES, for the design of the models the R software was used (R Foundation for Statistical Computing, 2016); based on the results obtained, the year in which the NCRES 50% generation goal will be reached is calculated. The data used to construct NCRES installed capacity growth curves, electric power generation with CES and NCRES were taken from Federal Ministry for Economic Affairs and Energy (BMWi, 2018) and Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE, 2018a; Fraunhofer ISE, 2018b). The legal and regulatory framework was made based on a bibliographic review of scientific articles, official reports and the regulation issued by the German government.

2.1. Legal and Regulatory Frameworks Related to NCRES in Germany

Table 1 presents a legal and regulatory framework that allowed Germany to incentivize NCRES generation projects; it marked its beginning with the Electricity Feed-In Law (1991), which evolved to allow investors, private or individual, to have sufficient incentives to invest in the installation of generation equipment and help in the growth of the NIEGC of Germany, which improved the reliability and competitiveness of the electric power market, combating climate change by reducing CO_2 emissions and promoting the dismantling of nuclear generators, strengthening sustainable energy growth and being environmentally friendly.

For many years Energiewende had the Feed-In Tariff (FiT) as its main mechanism (Pescia and Graichen, 2015), enabling it reach and to fulfill it's the growth objectives; the FiT changed according to the needs presented by the market (Anatolitis and Welisch, 2017), and initiated fixed rates for energy produced according to technology. This encouraged the installation of generation

Table 1: Legal and regulatory frameworks related to NCRES in Germany

Legal and regulatory frameworks	Commentaries
Electricity Feed-In Law (1991)	Generators with renewable energy sources gave priority to access to the network, with the purpose that public sector companies must buy in their entirety the energy generated under the established tariffs
Federal Building Codes for Renewable Energy Production (1997)	This program forced the network operators to build the necessary infrastructure to be able to transmit the energy generated by the offshore wind farms, thus making use of the marine wind resources and energizing the electricity sector
Loans - 100,000 roofs programme (1999)	Its objective was focused on creating 300 MW of photovoltaic generation, it was agreed to make loans to projects with low interest rates. The program ended in July 2003 with a total of 55,000 installations and 261 MW of installed capacity
RES Act (2000)	This law replaced the Electricity Feed-In Law (1991), its objective was to double the generation of renewable energy by the year 2010 and allow the sustainable development of energy supply in the interest of climate and environmental protection. The priority of access to the network of the NCRES facilities, the compulsory purchase and remuneration of energy NCRES was implemented. These guidelines will be maintained in all versions of the RES Act that are legislated
RES Act (2004)	It represents the first amendment that is made to the RES Act, it is established as an objective to increase to 12.5% the participation of the NCRES in the energy supply for the year 2010 and at least 20% for the year 2020; the rates established for the offshore wind and biomass installations were increased
RES Act (2009)	This amendment established the objective of achieving a 30% share of NCRES in the energy supply by the year 2020. The price of the FiT tariffs for onshore and offshore wind facilities was increased, also the wind energy producers were encouraged to sell their energy in the market instead of receiving their FiT rates Fees were established for landfill, wastewater and biomass reprocessing technologies, small biomass facilities and geothermal facilities
RES Act (2012)	It was proposed to promote the expansion of NCRES, to increase the cost efficiency and promote the integration of electrical systems related to NCRES. It was established as a goal of NCRES participation in the national electricity supply for 2020 to 35%, for 2030 to 50%, for 2040 to 65% and for 2050 to 80%.
RES Act (2014)	It was established as a goal of NCRES participation in national electricity consumption for 2025 to 40-45%, for 2035 55-60% and for 2050 for 80%. The installation of 2.5 GW of onshore wind power, 800 MW of offshore wind energy, 2.5 GW of photovoltaic solar energy and 100 MW of additional net biomass energy per year is proposed. Eliminates tariffs for new facilities and incorporates the auction mechanism as a method of allocating compensation for new facilities
RES Act (2017)	The remuneration of the renewable electric power is determined by the market offers, the projects are chosen by public auction organized and supervised by the Federal Network Agency. The winning projects will receive contracts for a period of 20 years for the sale of energy at the price they bid during the auction process

Sources: (Bruns et al., 2011; de Melo et al., 2016; BMWi, 2017; IEA, 2017) capacity, the inclusion of new technologies facilitating the evolution and diversification of the generation matrix, achieving a better use of available resources (Morris and Pehnt, 2012; Appunn, 2014; Bohringer et al., 2017). From the economic point of view, the FiT is considered an inefficient and unsustainable mechanism due to the price of energy established by law, it can infer in the free competition of the electricity market (Andor et al., 2017; De Vos, 2015). In the latest version of the EEG, it was decided to implement the auction and bidding mechanism for energy projects, to continue promoting the growth of NCRES technologies and seeking the reduction of the price of electricity (Morris and Pehnt, 2012; Pescia and Graichen, 2015; Fischer et al., 2016; Andor et al., 2017; Anatolitis and Welisch, 2017).

2.2. Feed-In Tariff

The Feed-In Tariff was the mechanism implemented by Germany to encourage the development of the NCRES (Pescia and Graichen, 2015), which consists in the payment of a fixed fee for the energy generated by NCRES. To improve effectiveness, priority was given to network access for all NCRES, total purchase of energy produced by network operators and stable purchase of energy for 20 years.

These elements strengthened the FiT and positioned Germany as one of the greatest powers; its biggest problem is in the increase in the final price of energy that consumers pay, which makes it an economically unsustainable mechanism (Andor et al., 2017; Morton and Peabody, 2010); the new auction scheme has encouraged projects with better prices and support the proposed technological migration (Dinkloh, 2014; Appunn, 2016; Bundesnetzagentur, 2018).

3. RESULTS

The German government encouraged the development of NCRES through the legal and regulatory framework. Table 2 shows in the growth of installed capacity 83% of NCRES compared to 17% of CES, the generation of electricity by means of these resources has been rising. The data of (BMWi, 2018) differ from the data presented in (Fraunhofer ISE, 2018a); the differences found are: (1) the values do not exceed 2% difference, (2) the data from (BMWi, 2018) present classification of the different sources of biomass (biogenic solid fuels, biogenic liquid fuels, biogas and biomethane, sewage gas, landfill gas) and (3) data from (BMWi, 2018) present 39MW of geothermal energy that are not presented by Fraunhofer ISE.

Table 2: Net installed electricity generation capacity in Germany at 2017

Source	GW	%	∑ (%)	Classification
Wind onshore	50,29	25	55%	NCRES
Solar	42,34	21		
Biomass	7,70	4		
Hydro Power	5,50	3		
Wind offshore	5,43	3		
Gas	29,85	15	45%	CES
Hard Coal	25,06	12		
Brown Coal	21,20	10		
Uranium	10,80	5		
Mineral Oil	4,34	2		

Data source: (Fraunhofer ISE, 2018a)

Table 2 presents the NIEGC of the year 2017, it is observed that the NCRES have a majority participation compared to the CES. According to European Comission (2008), it proposed the goals of 20% cut in greenhouse gas emissions (from 1990 levels), 20% of EU energy from renewables and 20% improvement in energy efficiency, the achievements were met and with excellent indicators, due to the great Germany's commitment and the effectiveness of the Energiewende.

3.1. Growth in Renewable Energy

Figure 1 presents the capacity data in MW and Figure 2 shows the energy generated in TWh with NCRES, data reported by (BMWi, 2018), the laws described in Table 1 were represented by dotted vertical lines. The greatest increases in capacity and generation with NCRES are presented in wind, solar and biomass resources; geothermal and hydraulic do not have significant variations because the hydraulic potential is almost exhausted and there is only perspective for small hydro power (Paish, 2002; Balat, 2006) and the geothermal potential has little development despite having a high potential (Purkus and Barth, 2011).

Tables 3 and 4 show the growth rate based on the year 2017, wind energy showed growth due to the increases in rates, the PV generation was strengthened due to the FiT tariffs implemented and smart metering (Christoforidis et al., 2013), and generation with biomass presents significant contributions in generation despite not having a high installed capacity such as wind resources and PV, achieving the highest efficiency when using different technologies (Brick & Thernstrom, 2016; BMWi, 2018).

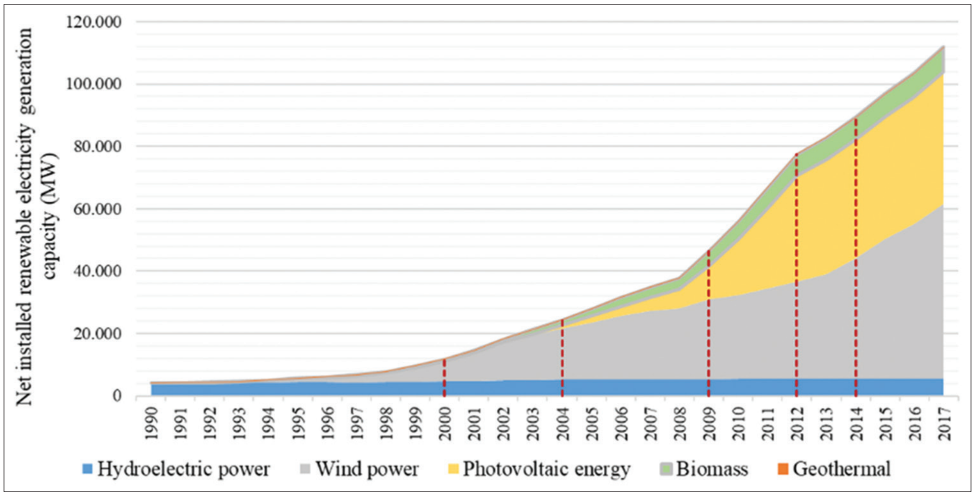
Taking the entry into force of the Kyoto Protocol (2005) as a reference, the Energiewende through the FiT allowed the installation from 2004 to 2017 of 39 GW of wind, 41 GW of photovoltaic and 6.3 GW of biomass; an increase in electricity generation of 80.9 TWh of wind, 39.4 TWh of photovoltaic and 40.6 TWh of biomass. These increases have allowed displacing the CES generation and meeting the goals set out in the European Commission and its regulation.

3.2. Forecast of Electric Power Generation 50% CES and 50% NCRES

Figure 3 presents the annual percentage of electric power generation in Germany with CES and NCRES, data reported by (Fraunhofer ISE, 2018b); it is observed how the generation with NCRES is on the rise, gradually displacing the generation with CES and approaching the point of generation 50% CES and 50% NCRES. This change was mainly due to the dismantling and modification of fossil power plants to enable a more flexible operation, the shutdown of nuclear power plants, the buildup storage and converter capacities for grid-stabilization and the expansion of the power lines for wind power (Wirth, 2018).

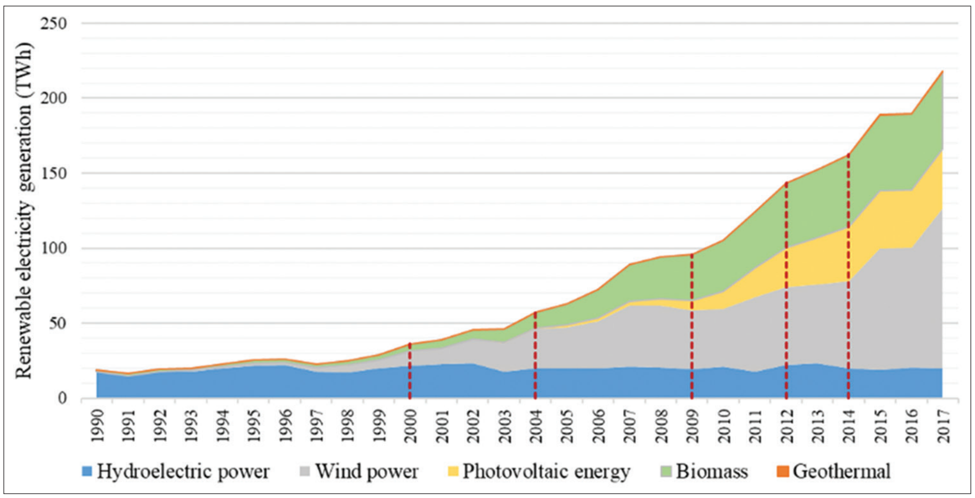
Using the percentage values presented in Figure 3, 2 time series are generated that allow analysis of the behavior of power generation with CES and NCRES, this data will allow the design of regression models to forecast the behavior for coming years. The software

Figure 1: Evolution of the renewable NIEGC in Germany



Data source: (BMWi, 2018)

Figure 2: Annual NCRES electricity generation in Germany



Data source: (BMWi, 2018)

Table 3: Net installed renewable electricity generation capacity in Germany

Sources	1990 (%)	2000 (%)	2004 (%)	2009 (%)	2012 (%)	2014 (%)	2017 (%)	2017 (MW)
Wind	0.10	10.91	29.38	46.05	55.44	69.11	100	55876
Photovoltaic	0.00	0.27	2.61	24.92	80.38	89.40	100	42394
Biomass	1.62	8.80	21.12	60.99	84.55	90.90	100	7987

Table 4: Annual renewable electricity generation in Germany

Sources	1990 (%)	2000 (%)	2004 (%)	2009 (%)	2012 (%)	2014 (%)	2017	2017 (TWh)
Wind	0.07	9.10	24.40	36.97	48.47	54.87	100	107
Photovoltaic	0.00	0.15	1.40	16.50	66.12	90.38	100	40
Biomass	2.79	9.21	20.37	59.65	84.09	93.98	100	51

R (R Foundation for Statistical Computing, 2016) was used to estimate the models.

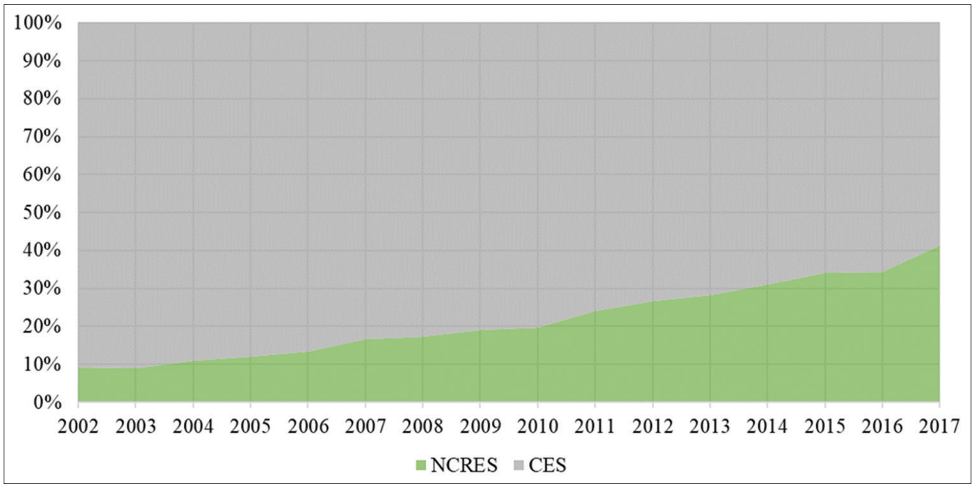
Tables 5 and 6 are the results of the regressions carried out, in the models it is observed that the p-value for the coefficient and the constant are lower than 0.01, which guarantees the relevance of the coefficient and the constant for the model. The models are expressed as:

$$\text{NCRES (\%)} = 0.02077 \cdot \text{Year} - 41.51895 \quad (1)$$

$$\text{CES (\%)} = -0.02077 \cdot \text{Year} + 42.51895 \quad (2)$$

Figure 4 shows the behavior of electricity generation, increasing for NCRES and decreasing for CES, and the forecast of models (1) and (2) until 2025. The cut of the two lines indicates the date in which a total annual generation of 50% NCRES and 50% CES will be obtained.

Figure 3: Percentual relation between the annual electricity generation with CES and NCRES



Data source: (Fraunhofer ISE, 2018b)

Figure 4: Regression models of the annual electricity generation with CES and NCRES

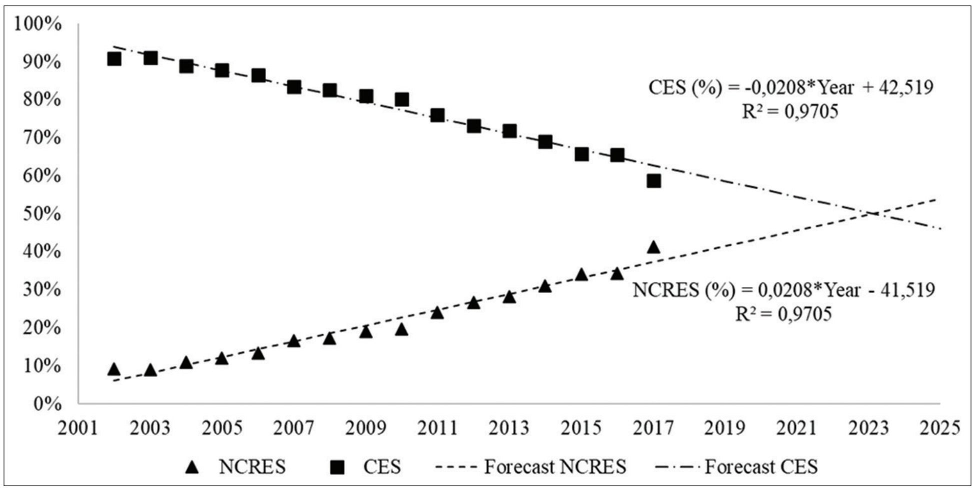


Table 5: Results of the regression model to NCRES

Coefficient	Estimate	Std. error	t value	P-value
(Intercept)	−41.51895	1.94505	−21.34592	0.00000
Year	0.02077	0.00097	21.45747	0.00000

Table 6: Results of the regression model to CES

Coefficient	Estimate	Std. Error	t value	P-value
(Intercept)	42.51895	1.94505	21.86004	0.00000
Year	−0.02077	0.00097	−21.45747	0.00000

To obtain the generation year 50% NCRES and 50% CES, it was equaled (1) with (2) and the variable year was cleared. When carrying out the mathematical operations, the value of 2023.1326 was determined, in other words, the statistics of electricity generation of the year 2023 will have a behavior equal to or greater than 50% with NCRES and a behavior equal to or less than 50% with CES, and the goal of the 50% generation with NCRES will be accomplish.

4. CONCLUSIONS

In the research the legal and regulatory framework of Germany was presented, the methodology used analyzed the data of installed capacity and total annual generation. It was observed that the Energiewende and its FiT mechanism for the promotion of the NCRES developed an organized process, based on competitive conditions for each of the available technologies and resources, without neglecting the different sectors of the market; the German state maintained its role as regulator, without losing sight of the proposed goals, seeking alternatives to maintain, promote and increase the efficiency and competitiveness of activities and meeting the needs of demand.

According to the reported data, Germany has a Net installed electricity generation capacity composed of 55% with NCRES and 45% CES; and its electricity generation has a ratio of 41% and 59% respectively. From the models obtained, a behavior of the increasing generation for NCRES and decreasing for CES is forecast, additionally it predicts that by the year 2023 a 50%-50% relation will be reached, which will exceed the 2030 date proposed by (RES Act, 2012). The results allow us to distinguish Germany's commitment and the effectiveness of its legal and regulatory framework.

For future research, the real behavior of the electric power generation will be analyzed against the results obtained by the models (1) and (2), in order to validate the forecasting capacity; this methodology will be used for other European countries due to the commitments acquired in the European Commission.

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