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The Relationship Between Renewable Energy Consumption and Economic Growth in France: a Necessary Condition Analysis

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Abstract
This study offers a novel analytical approach on the relationships between renewable energy consumption, capital, labor force, new firm formation rate, and economic growth. It aims to investigate such causal relationships using different estimation techniques such as the ordinary least squares (OLS) model, dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and canonical cointegrating regression (CCR), along with necessary condition analysis (NCA), which are applied to data for France over the period 1987–2017. Our results show that all necessary conditions yield outcomes ranging from small- to large-sized effects on economic development. The French government should readdress its efforts towards encouraging more beneficial investments in renewable energy consumption. This study opens up new insights for policymakers to maintain environmental protection and ensure sustainable economic growth. Finally, the use of NCA reduces complexity and allows a better understanding of the relationships involved.

Keywords Necessary condition analysis · Economic growth · Renewable energy · New firm formation rate

1 Introduction

Renewable energy is an essential element for both economic development and the environment. As argued by Andreas et al. [6], it is an indispensable factor in sustaining and increasing the level of economic growth of a country. In its 2030 strategy, the European Union (EU) has decided to reach a target of 27% renewable energy in its global energy consumption. Furthermore, France envisages that renewable energy sources will account for at least 32% of its gross electricity consumption by the year 2030. Moreover, in 2016, renewable energies in France represented roughly 15.7% of the worldwide energy use. The share of renewable energy has also increased to 57% [76]. This evolution induces a decrease in the commercial deficit and encourages investment to achieve lower CO_2 emissions. Moreover, after the Paris Climate Change Conference in 2015, the French government became a front runner among the EU member states aiming to promote climate change mitigation and a significant reduction in greenhouse gas emissions. In this context, the present study sets out to identify the necessary conditions concerning the prospects for renewable energy and French economic growth.

Our article investigates the relationship between economic growth, renewable energy consumption, labor force, capital, and the new firm formation rate by using complexity theory along with necessary condition analysis (NCA). Complexity theory is employed to explain the non-linear, heterogeneous and dynamic mechanisms of complex phenomena in various fields (e.g., management, economics, and finance). Complex causality and necessary condition analysis has started to attract the attention of many researchers [37, 71, 72]. Necessary condition analysis (NCA) describes a sufficient condition to produce a given outcome; a necessary cause allows the outcome to exist. Conversely, without the necessary cause, the outcome will not occur, and other factors could be involved [86]. In addition, NCA can identify both critical predictors and critical levels of necessary conditions that must be present to attain the desired outcome [34].

The present contribution enriches the existing literature in three main ways. To the best of our knowledge, our study represents the first empirical attempt that uses the NCA approach to investigate the nexus (see Table 1). Currently, many proponents of statistical methods suggest that it is necessary to

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Table 1 Summary of the relationships between renewable energy consumption and economic growth

Author(s)	Country/region	Sample period	Methodology	Main findings
Apergis and Payne [8]	20 OECD countries	1985–2005	FMOLS technique and Granger causality test	Bidirectional linkage between REC and economic growth in both the short- and long-run
Menegaki [58]	27 European countries	1997–2007	Random effect	Neutrality
Apergis and Payne [10]	16 countries	1990–2007	FMOLS technique and Panel Cointegration test	Unidirectional linkage from economic growth to renewable electricity consumption in the short-run and bidirectional relationship in the long-run
Tugcu et al. [85]	G7 countries	1980–2009	Cointegration and Hatemi-J causality	Long-run equilibrium association among renewable energy and growth in all G7
Marques and Fuinhas [57]	24 European countries	1990–2007	Ordinary least squares and panel corrected standard errors	Renewable energy has a positive effect on economic development
Pao and Fu [66]	Brazil	1980–2010	Cointegration and VEC	Unidirectional relationship from renewable energy to economic growth
Sebri and Ben-Salha [77]	BRICS countries	1971–2010	ARDL approach and vector error-correction model	Long-run equilibrium relationships among variables
Lin and Moubarak [53]	China	1977–2011	Cointegration and VEC	Feedback
Salim et al. [74]	OCDE countries	1980–2011	Cointegration, DOLS, and panel Granger causality	Unidirectional linkage between GDP growth and renewable energy consumption
Omri et al. [63]	17 developed countries	1990–2011	2SLS, 3SLS, and GMM	There is a unidirectional causality running from renewable consumption to economic development in Hungary, India, Japan, Netherlands, and Sweden. A bidirectional relationship is supported in Belgium, Bulgaria, Canada, France, Pakistan, and the USA, while no causality exists in Brazil, Finland, and Switzerland.
Shahbaz et al. [79]	Pakistan	1972Q1–2011Q4	ARDL model, cointegration, and VEC	Bidirectional relationship between REC and economic growth
Ben Jebli and Ben Youssef [18]	Tunisia	1980–2009	ARDL approach and VEC	The existence of a short-run unidirectional linkage between renewable energy and economic growth
Bloch et al. [23]	China	1980–2009	ARDL and VEC model	Renewable energy improves economic growth
Aslan and Oguz [12]	New EU member 7 countries	1980–2009	Hatemi-J causality test and ARDL approach	REC has a positive effect on economic growth for all investigated countries.
Kahia et al. [46]	MENA net oil exporting countries	1980–2012	Panel cointegration approach	Bidirectional linkage between renewable energy and economic development
Inglesi-Lotz [43]	OECD countries	1990–2010	Panel cointegration, fixed effect, and pooled estimation	Renewable energy consumption. A significant positive effect on the economic growth

Table 1 (continued)

Author(s)	Country/region	Sample period	Methodology	Main findings
Koçak and Şarkgüneşi [49]	9 Black Sea and Balkan countries	1990–2012	Panel cointegration test, DMOLS, and FMOLS approach	Long-term balance between renewable energy consumption and economic growth and renewable energy consumption, with a positive impact on economic growth. Heterogeneous
Narayan and Doytch [60]	89 countries	1971–2011	GMM approach	Bidirectional relationship between renewable energy and economic growth for these countries
Destek et al. [30]	17 emerging countries	1980–2012	Bootstrap panel Granger causality	Renewable energy leads to economic growth in Peru, Greece, and South Korea.
Berk et al. [20]	14 European Union countries	1990–2014	GMM approach	Absolute and conditional convergence of energy consumption across the EU countries
Wang et al. [88]	Pakistan	1990–2014	2SLS approach	Renewable energy consumption does not improve the situation of the human development process.
Atems and Hotaling [13]	174 countries 1980–2012.	1980–2012	GMM approach	Positive and statistically significant relationship between renewable electricity production and growth

Notes: *ARDL* autoregressive distributed lag, *DOLS* dynamic ordinary least squares, *GMM* generalized methods of moments, *VECM* vector error-correction, *FMOLS* fully modified ordinary least squares, *2SLS* two-stage least squares, *3SLS* three-stage least squares have a detailed insight on the studied cases. In addition, several models have been criticized for their unrealistic assumptions, such as multicollinearity, multivariate normality, and homoscedasticity, which did not hold for real applications [17, 55, 90]. To overcome such limitations, researchers require alternative procedures, such as the necessary condition analysis [34]. Secondly, the present study extends the existing empirical literature on the relationships and causality between renewable energy consumption and economic growth in France, with the aim of helping policymakers to better understand the role of renewable energy in the economic development process. Thirdly, studying the relationships between economic growth, renewable energy, capital, and labor force without including additional variables will result in a biased estimation of coefficients and problems due to omitted variables. To overcome these drawbacks, our study includes the number of new firms created. Therefore, we build upon the available literature by examining for the first time the dynamic causal links between these variables and economic growth.

This paper is organized as follows. Section 2 presents a literature review and some working hypotheses. Section 3 describes the methodology. Section 4 summarizes and discusses the empirical results. Section 5 sets out the conclusions as well as some policy suggestions.

2 Literature Review

Yang and Zhao [91] empirically investigated the relationship between energy consumption, CO_2 emissions, and economic growth in India using multivariate Granger causality tests. Shahbaz et al. [80] studied the relationship between energy consumption and economic growth for 11 countries for the period 1972–2013. Adams et al. [2] found a positive relationship between energy consumption and economic growth base on panel data for 16 sub-Saharan African countries. Alam et al. [5] used the autoregressive distributed lag (ARDL) bounds test approach to explain the impacts of income, energy consumption, and population growth on CO_2 emissions for India, Indonesia, China, and Brazil. Bouznit and Pablo-romero [25] examined the causality between CO_2 emissions and economic growth in Algeria, taking into account energy use, electricity consumption, exports, and imports. Their empirical results indicate that an increase in energy use and electricity consumption increases CO_2 emissions, and suggest the promotion of renewable energies and energy efficiency policies. Yu et al. [92] have explained the causality between the real GDP per capita and renewable energy consumption for Taiwan and 24 countries belonging to the Organization for Economic Cooperation and Development (OECD) from 1980 to 2011. Andreas et al. [6] investigated the causal relationship between economic growth and the expansion of renewable electricity for 28 European Union countries (EU) during the recent financial crisis (2008–2013). Their results suggest that renewable energy transitions are promoted by EU countries. Abdulrashid and Ozturk [1] studied the impact of renewable energy on the economic growth of Germany. Their results show that renewable energy consumption in Germany consolidates the country's economic growth prospects, yielding a 1% increase in renewable energy consumption, which boosts German economic growth by 0.2194%. Bhattacharya et al. [22] analyzed the effects of renewable energy consumption on the economic growth of the major renewable energy–consuming countries worldwide. These authors argue that renewable energy consumption has a significant positive impact on economic growth and encourage governments and international institutions to increase renewable energy investment and consumption. Apergis and Payne [8] show the existence of a bidirectional relationship between renewable energy consumption and economic growth in both the short- and long-run. Rafiq and Salim [70] recommend that, while India may directly encourage energy conservation measures, China and Thailand may opt for a balanced combination of some alternative strategies. Tansel et al. [83] test the causal relationship between renewable and non-renewable energy consumption and economic growth in G7 countries from 1980 to 2009 using the autoregressive distributed lag approach and including research and development indicators. Apergis and Payne [9] analyzed the relationship between renewable and non-renewable energy consumption and economic growth for 80 countries using a multivariate panel framework from 1990 to 2007. These authors' findings establish the existence of bidirectional causality between renewable energy and economic growth in both the short- and long-run. Shafiei and Salim [78] examined the nexus between the determinants of pollution in OECD countries over the period 1980–2011. Their empirical results reveal that non-renewable energy consumption increases CO_2 emissions, whereas renewable energy consumption decreases pollution. Dumas et al. [39] show that political transitions could have large effects on the development of renewable energy and environmental pollution over time, influencing the ability of countries to reach various climate mitigation trajectories. Rafindadi [69] explored the nexus between economic growth, energy consumption, financial development, trade openness, and CO_2 emissions in Nigeria. The findings of this author reveal that financial development increases energy consumption but can lower pollution levels. Brini et al. [26] investigated the dynamic relationships between renewable energy consumption, international trade, oil price, and economic growth. Their results confirm a bidirectional relationship between renewable energy consumption and international trade in the short-run. The latter authors find evidence for a unidirectional relationship between renewable energy and oil price in the short term. Furthermore, the relationship between renewable energy and economic growth has attracted considerable attention and has been intensively examined in recent studies. Tugcu and Topcu [84] tested the linkage between the renewable, the non-renewable energy consumption, and the economic growth in G7 countries. Their results reveal that the energy-growth nexus in the G7 countries are characterized by a negative environmental effect. Ben Jebli and Ben Youssef [19] analyzed the dynamic causality between pollution, real gross domestic product, and non-hydroelectric renewable energy consumption in Argentina over the period 1980–2013. Their results show that there are long-term bidirectional causalities between all the considered indicators. Wang et al. [88] used the two-stage least square method to probe the causal link between renewable energy consumption and the human development index for the period 1990–2014 in Pakistan. Their findings show that renewable energy consumption does not advance the situation of the human development process in Pakistan. Aydin [14] examined the relationship between the renewable and non-renewable electricity consumption and economic growth. This author concludes that policymakers should encourage renewable consumption in order to reduce energy dependence and sustain economic growth. Ji and Zhang [45] focus their attention on China and emphasize the role of financial development in supporting the renewable energy sector. Their empirical results show that financial development is particularly essential and contributes to increasing the growth of renewable energy. Keček et al. [48] investigated the economic effects of the deployment of renewable energy systems in Croatia. These authors found that there are positive multiplicative impacts between economic development and technologies based on certain renewable energy sources. Mohamed et al. [59] use the autoregressive distributed lag approach and the Granger causality to examine the causal relationship between renewable or fossil energies and terrorism (in particular, the link with terrorism in France for the period 1980–2015). They found long-run relationships between the considered variables. Using panel data from the 19 nations of the G20 countries from 1990 to 2014, Qiao et al. [68] applied the fully modified ordinary least squares (FMOLS) model to estimate the effects of the agriculture-economic growth-renewable energy nexus on pollution, confirming that renewable energy consumption reduces CO_2 emissions. Ozcan and Ozturk [65] explored the link between renewable energy consumption and economic growth in 17 emerging countries, indicating that this relationship neutral in 16 countries while the growth hypothesis is only supported in the case of Poland.

In addition, several studies have associated capital and labor with economic growth [2, 15, 64, 73, 80]. Apergis and Payne [8] analyzed panel data from 25 countries over the period 1985 to 2005. Their results indicate a positive significant impact of capital and labor on economic development. Ayres and Voudouris [15] examined the causality between capital, labor force, energy, and economic growth in the USA, UK (United Kingdom), and Japan. The results show a positive relationship between gross fixed capital formation, labor force, and economic growth.

By exploring the links between new firm formation rate and economic growth, Van Stel et al. [87] investigated whether or not entrepreneurial activity influences GDP growth in a sample of 36 countries. These authors find that the entrepreneurial activity of young businesses affects economic development. Aghion et al. [3] show that new firm formation rate has a positive impact on the productivity growth of domestic firms. Lee et al. [52] indicate that a high rate of new firm formation can be associated with a dynamic regional economy. Liu [54] employed an error-correction model (ECM) to investigate the determinants of UK corporate failures from1966 to 1999. Their findings indicate a significant causality between bankruptcy and macroeconomic variables. Hernandez Tinoco and Wilson [42] developed risk models for financial distress prediction and bankruptcy based on the macroeconomic environment. Their results reveal that a weak macroeconomic environment increases the number of failed firms. Kuckertz et al. [50] used fuzzy-set qualitative comparative analysis to test the causality between entrepreneurial activity and economic growth. The results suggest a positive and significant correlation. According to du Jardin [33], unstable forecasts in bankruptcy prediction are the result of changes occurring within the economic environment between the period during which a machine learning model is designed and the period when it is applied. Boratyńska [24] shows that, in many countries, a close correlation exists between the business cycle and liquidation.

Based on a literature review, this study proposes the following necessary conditions:

Proposition 1: Renewable energy is necessary for economic growth.
Proposition 2: Capital is necessary for economic growth.
Proposition 3: Labor force is necessary for economic growth.
Proposition 4: New firm formations are necessary for economic growth.

3 Methodology

3.1 Necessary Condition Analysis

Necessary condition analysis (NCA) introduced by [34] has been recently developed and has drawn the attention of different behavioral science disciplines, such as entrepreneurship [11], human resource management [41], psychology [47, 81], and operations [82, 86]. NCA creates a quantitative measure of the level of the necessary condition and determines the degree of condition X that is necessary for a given level of outcome condition Y [35]. The NCA pulls an "envelope" based on the sample in three-dimensional space and a line in two-dimensional space. The ceiling $Y = f(X)$ is the border between an empty field without observations and a field containing observations. The ceiling method is different from the conventional regression where a line (2D) or surface (3D) is drawn through the middle of the dataset. The necessary condition X for outcome Y is mathematically expressed by the inequality $Y \leq f(X)$: all observations are on or under the ceiling. Dul [34] recommends drawing the ceiling line with the Ceiling Envelopment–Free Disposal Hull (CE-FDH) technique. This line is a non-decreasing linear function that connects the upper-left observations of the XY plot. Another suggested method is the Ceiling Regression–Free Disposal Hull (CR-FDH), which draws an OLS regression line through the observations that connect the linear portions of the CE-FDH ceiling line. The necessary condition can be measured in terms of the effect size (d), which is the space of the "empty" zone above the ceiling zone relative to the total space in which observations can be theoretically expected or empirically observed. The effect size of a necessary condition can have the values between 0 and 1. Dul [34] suggests evaluating the effect sizes as follows: $0 < d < 0.1$ a "small effect," $0.1 < d < 0.3$ a "medium effect," $0.3 < d < 0.5$ a "large effect," and $d > 0.5$ a "very large effect." In addition, the "bottleneck table" of NCA is another representation which specifies the level of the necessary condition that is separately necessary to attain a certain desired level of outcome [34].

3.2 Data and Variables

In this study, we use annual data for France covering the period 1987–2017 collected from World Development Indicators [89], as well as from the Organization for Economic Cooperation and Development [62] and the French National Institute of Statistics and Economic Studies [44]. Following the approach adopted in previous empirical studies, this paper uses the real GDP per capita (GDP) as the outcome variable measured in millions of constant 2010 US dollars. Necessary conditions include the gross fixed capital formation, expressed in constant 2010 US dollars, as a proxy for capital (GFC), a labor variable measured by the total labor force defined as the economically active population (TLF), renewable energy consumption (total final energy consumption) in thousands of metric tonnes (REC), and the number of new firm formations (NFF). Summary statistics and the correlation matrix are shown in Tables 2 and 3, respectively.

Following Bouznit and Pablo-Romero [25] and Adams et al. [2], we transform our data into logarithms and the model is developed as follows:

Table 2 Descriptive statistics

	GPD	GFC	NFF	REC	TLF
Mean	10.529	26.952	12.629	9.786	10.194
Median	10.573	26.997	12.398	9.747	10.205
Maximum	10.658	27.180	13.340	10.109	10.297
Minimum	10.290	26.605	12.263	9.574	10.063
Std. Dev.	0.109	0.174	0.412	0.148	0.067
Skewness	−0.607	−0.326	0.731	0.822	−0.263
Kurtosis	1.986	1.639	1.751	2.559	2.172
Jarque-Bera	3.232	2.943	4.777	3.743	1.244
Observations	31	31	31	31	31

$$\ln GPD_t = \alpha_1 + \alpha_2 \ln REC_t + \alpha_3 \ln GFC_t + \alpha_4 \ln TLF_t + \alpha_5 \ln NFF + \varepsilon_t.$$

4 Empirical Results and Discussion

4.1 Multivariate Regression

Following Koçaka and Şarkgüneşi [49] and Ahmad and Du [4], the nexus is investigated here using the ordinary least squares (OLS), the dynamic ordinary least squares (DOLS), and the fully modified least squares techniques, as well as the canonical cointegrating regression (CCR). The first step of our analysis is to explore the stationarity of variables used in the study. In this context, the presence/absence of a unit root is ascertained using the augmented Dickey-Fuller (ADF) test of Dickey and Fuller [32] and the Phillips-Perron (PP) test of Phillips and Perron [67]. ADF and PP test the null hypothesis of non-stationarity against the alternative hypothesis of the absence of a unit root (stationarity). Table 4 reports the results for panel unit root tests. We conclude that all variables are integrated of order (1). This leads us to examine the hypothesis of cointegration between real GDP, renewable energy, capital, labor, and new firm formation using Johansen's test procedure.

Table 3 Correlation matrix

	GPD	GFC	NFF	REC	TLF
GPD	1				
GFC	0.975	1			
NFF	0.684	0.736	1		
REC	0.486	0.512	0.840	1	
TLF	0.963	0.941	0.789	0.665	1

Table 4 Unit root test

	ADF		PP	
	Intercept	Intercept and trend intercept	Intercept	Intercept and trend intercept
lnGDP	− 3.143	− 1.743	− 2.8733	− 1.802
ΔlnGDP	− 3.812***	− 3.967**	− 3.751***	− 3.832**
lnREC	− 0.653	− 2.077	− 0.653	− 1.923
ΔlnREC	− 6.349***	− 6.643***	− 6.544***	− 7.830***
lnGFC	− 1.656	− 2.589	− 1.591	− 2.127
ΔlnGFC	− 3.694***	− 3.540***	− 3.563**	− 3.326**
lnTLF	− 1.355	− 3.083	− 1.943	− 3.010
ΔlnTLF	− 5.572***	− 5.672***	− 6.042***	− 6.448***
lnNFF	− 0.056	− 1.679	− 0.056	− 1.730
ΔlnNFF	− 4.697***	− 4.792***	− 4.697***	− 4.776***
Critical value				
1%	− 3.670	− 4.296	− 3.670	− 4.296
5%	− 2.963	− 3.568	− 2.963	− 3.568
10%	− 2.621	− 3.218	− 2.621	− 3.218

Note: Automatic lag selection based on SIC with maxlag of 7

In the second step, we apply Johansen's cointegration test procedure (1991) to examine whether or not economic growth, renewable energy, capital, labor, and new firm formation are cointegrated. The results reported in Table 5 show that the null proposition of no cointegration is rejected, meaning that cointegrating vectors exist in the model vector because the value of the trace statistic is higher than the related critical value. These findings indicate the presence of a long-run relationship between the variables.

Table 6 shows the results for all the models. For the OLS regression, we find that REC has a significant impact on GDP. The sign of REC is negative, which contradicts our theoretical expectations and most previous studies reported in the literature (e.g., [1, 6, 13]). Overall, the OLS results fail to support H4. Concerning the control variable, the model estimations confirm that new firm formation does not have a significant impact on economic growth. This is in sharp contrast to the results of Aghion et al. [3] and Van Stel et al. [87]. According to the DOLS results, only renewable energy and total labor force have a negative and significant impact on economic growth. The results of DOLS show that the impact of GFC and NFF on GDP are insignificant. For the FMOLS regression, only REC, GFC, and TLF have a significant impact on GDP, where a 1% increase in the labor force tends to increase the GDP by 1.264%. The sign of NFF is negative. This result is inconsistent with the observed correlation with GDP and findings in the existing literature [28, 29]. In the case of CCR, the long-run results show a significant effect of REC, GFC, and TLF on GDP in France. However, the results from DOLS, FMOLS, and CCR are no better than the results from OLS. In addition, our findings are in contrast with Lee [51] and Narayan et al. [61], who adopted and preferred DOLS and FMOLS rather than OLS. In practice, when some degree of multicollinearity is detected, conventional regression models are commonly used. Bastien et al. [16] point out that the inconvenience of these techniques is the exclusion of independent variables strongly correlated with the response variable. Instead, researchers have proposed a complex theory to overcome such limitations [34, 71, 90].

Table 5 Results of Johansen's cointegration test procedure

Null hypothesis	Trace statistic	0.05 critical value	Prob**
None*	99.735	66.818	0.000
At most 1*	54.902	47.856	0.009
At most 2	20.402	29.797	0.396
At most 3	8.567	15.494	0.406
At most 4	0.162	3.841	0.687

Notes: *Rejection of the hypothesis at the 0.05 level, **MacKinnon et al. [56] *p* value, The lags interval (expressed in first differences), 1 to 1

4.2 NCA Results

Following the approach described by Dul [34], we apply NCA to our dataset to investigate whether certain levels of renewable energy consumption, gross fixed capital formation, total labor force, and new firm formation rate are necessary to achieve high economic growth.

Table 6 Estimation of coefficients using OLS, DOLS, FMOLS, and CCR

Variables	OLS	Prob	DOLS	Prob	FMOLS	Prob	CCR	Prob
REC	− 0.101**	0.011	− 0.336***	0.003	− 0.128**	0.014	− 0.153**	0.030
GFC	0.291***	0.000	− 0.046	0.679	0.247***	0.000	0.218**	0.015
TLF	1.111***	0.000	2.072***	0.000	1.264***	0.000	1.323***	0.000
NFF	− 0.020	0.161	0.025	0.421	− 0.019	0.317	− 0.009	0.673
C	− 7.405***	0.000	− 6.390***	0.000	− 7.529***	0.000	− 7.218***	0.000
Adjusted R^2	0.985		0.993		0.984		0.980	

In this study, we made use of the NCA package in R [36]. NCA applied along with CE-FDH and CR-FDH indicates that each of the four single conditions necessarily has an effect size greater than zero (Table 7). Dul [34] suggests using a CE line for discrete datasets and a CR line for continuous datasets. In particular, we obtain full support for the first necessary condition relative to the effect sizes for renewable energy consumption (0.131–0.159). We find similar results using the estimated p value recommended by Dul et al. [38], which lies within the range of 0.009 to 0.012 for the CE-FDH and the CR-FDH methods. In addition, the ceiling line in Table 7 shows that renewable energy consumption has a positive impact on economic development; the coefficient implies that a 1% increase in the volume of RE will lead to 0.311% rise in GDP. Our results are consistent with the current literature [1, 6, 26, 59, 92], which propose that renewable energy consumption consolidates a country's economic growth prospects. On the one hand, we find full support for the effect of the second necessary condition (p value = 0.000); capital shows large effect sizes (0.462–0.425) above the d = 0.3 threshold value recommended by Dul [34]. Furthermore, the coefficient for GFC (0.598) means that, on average, an increase in capital by 1% will increase the GDP by 0.598%. This result is in agreement with the literature (see, e.g., [2, 15]). Moreover, the effect size for TLF is 0.415 when using the CR-FDH line, indicating a large effect on economic growth. In addition, the coefficient obtained with a ceiling line confirms that the labor force has a positive and significant impact on France's economic growth. This is intuitively in accord with previous research [8]. Concerning the control variable, the number of new firm formations has only a small effect on economic growth (0.107–0.119). The coefficient implies that a 1% increase in NFF contributes almost 0.096% to GDP. The estimated results are consistent with those of Lee et al. [52], showing that the level of NFF enhances economic development.

Figure 1 presents scatter plots of the necessary condition analysis for gross fixed capital formation, total labor force, renewable energy consumption, and the new firm formation rate. The CE-FDH and CR-FDH ceiling lines are also shown. Again, we can see that the upper-left corner of the plot is empty, which means that the four necessary conditions may exist. In addition, Table 8 is a "bottleneck table" [34] which describes the threshold levels of the four necessary conditions that are independently necessary (but not sufficient) to reach a certain desired level of economic growth. These levels indicate the percentages of the conditions ranging between the lowest and highest values observed in the dataset, and are

Table 7 Results of necessary condition analyses

Construct	Method	Effect size (d)	p value	Accuracy	Ceiling zone	Ceiling line
REC	CE-FDH	0.131***	0.009	100%	0.026	NA
	CR-FDH	0.159**	0.012	67.7%	0.031	GPD = 0.311 REC + 7.545
GFC	CE-FDH	0.462***	0.000	100%	0.013	NA
	CR-FDH	0.425***	0.000	64.5%	0.011	GPD = 0.598 GFC − 5.589
TLF	CE-FDH	0.4418***	0.000	100%	0.013	NA
	CR-FDH	0.415***	0.000	54.8%	0.012	GPD = 1.605 TLF − 5.834
NFF	CE-FDH	0.107***	0.000	100%	0.024	NA
	CR-FDH	0.119***	0.004	77.4%	0.024	GPD = 0.096 NFF + 9.383

Notes: $0 < d < 0.1$ "small effect", $0.1 \leq d < 0.3$ "medium effect", $0.3 \leq d < 0.5$ "large effect", $d \geq 0.5$ "very large effect"

* implies significance at 10% level, ** at 5% level and *** at 1% level

NA non-available

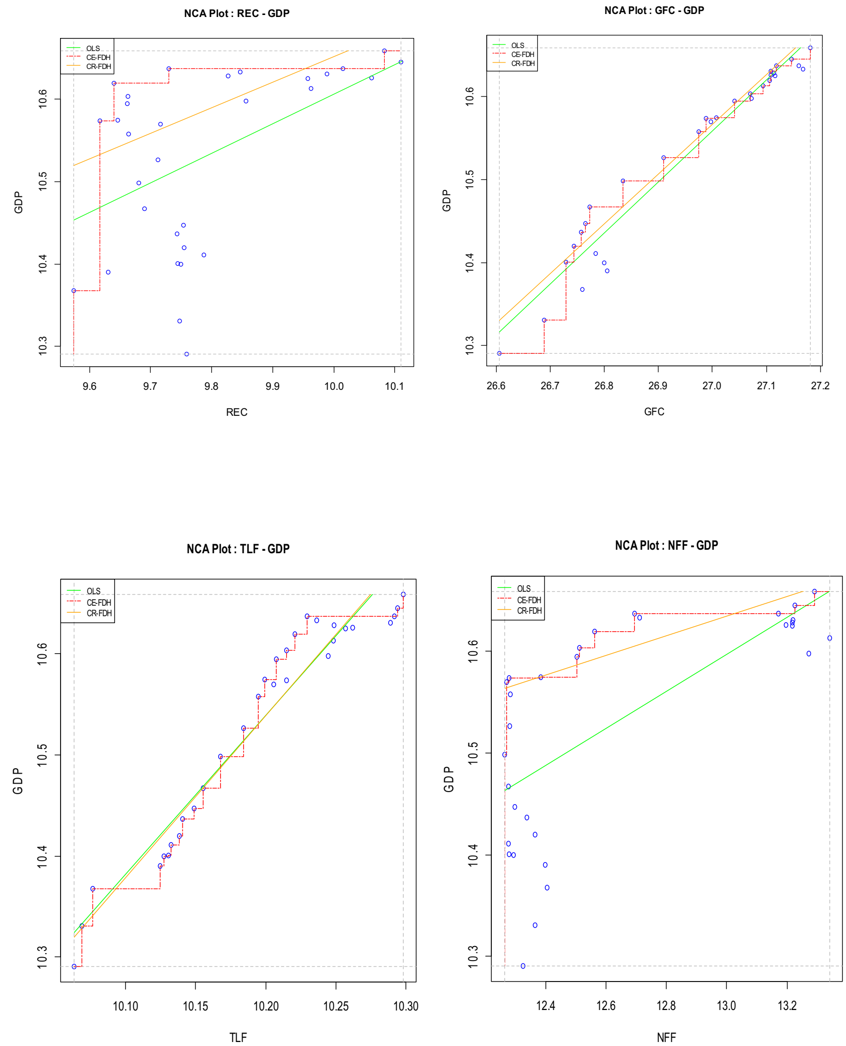

Fig. 1 Scatterplots of necessary condition analysis (NCA)

calculated using the CR technique illustrated in Fig. 1 [86]. The bottleneck table indicates that only the total labor force and gross fixed capital formation are necessary conditions for a low level of the outcome (GPD = 10). Consequently, such a condition makes a significant contribution to France's economic growth. As indicated in Table 8, all four conditions are necessary, while showing considerable levels (between 83.9 and 100), to reach the highest level of the outcome (GPD = 100). Renewable energy consumption is necessary for GPD = 70, capital is necessary for GPD ≥ 10, labor force is necessary for GPD ≥ 10, and new firm formations are necessary for GPD ≥ 60. For example, for the highest level of GPD = 100, the required minimum levels of the conditions are 83.9.5, 100, 90.1, and 95.3, respectively. Consequently, the French government and managers confronted with condition inefficiency could redirect their attention to invest in bottleneck conditions, especially to increase renewable energy consumption. As such, the results reveal valuable insight into the extent to which countries make efficient use of their resources. French energy policy, redefined by the objectives of the transitional law for green growth, is undergoing profound changes. Electricity production is currently mainly nuclear, but must be prepared for the gradual shutdown of the oldest nuclear power plants, while allowing the gradual integration of renewable energy sources. Heat production should

Table 8 Bottleneck levels (in %) using CR-FDH (NN not necessary)

GDP	REC	GFC	TLF	NFF
0	NN	NN	NN	NN
10	NN	14.5	2.0	NN
20	NN	21.4	11.8	NN
30	NN	24.1	21.6	NN
40	NN	27.7	31.4	NN
50	NN	39.9	41.2	NN
60	NN	53.0	51.0	0.7
70	17.5	64.2	60.8	0.7
80	39.7	75.7	70.6	22.2
90	61.8	87.4	80.4	40.0
100	83.9	100	90.1	95.3

contribute more strongly to the objective of decarbonizing the French energy mix than it does today. Thus, it would be possible to overcome the fragmented nature of this sector, which aggregates multiple erroneous individual decisions. Moreover, the empirical results show positive significant evidence for the role of NFF in accelerating economic growth. Along these lines, the French government needs to improve and increase the financial support to small and medium-sized enterprises. Moreover, decision-makers are required to control the monetary policy that plays a vital role in attracting entrepreneurship and propelling growth.

The classical econometric models used in this study (e.g., ordinary least squares regression) require that all variables contribute to the GDP outcome. However, the results estimated from the models may be incorrect if relevant predictors are excluded or omitted from the model [7, 75]. In addition, the multicollinearity between variables leads to two difficulties. First, important variables such as NFF and GFC become nonsignificant when using DOLS, FMOLS, and CCR. Second, the variable REC shows a negative coefficient in the OLS, FMOLS, and CCR estimators, while it has a positive influence on economic growth. However, NCA allows us to obtain a coherent model at the level of the coefficients while retaining all variables.

5 Conclusion and Policy Implications

This study uses classical econometric models and NCA to analyze the association between the outcome represented by "economic growth" and four necessary conditions. The analysis provides a decisive picture of the role of renewable energy consumption in France. Crucially, the causal relationships identified across the four conditions support our hypothesis in using the NCA approach. However, the results of OLS regression show that only REC, GFC, and TLF contribute to the economic growth. The DOLS regression reveals that REC and TLF are the unique variables having a significant impact on economic growth. On the other hand, according to the FMOLS regression, REC, TLF, and GFC have an effect on economic development. Finally, in the CCR regression, REC, TLF, and GFC have a significant impact on the GDP.

This study aims to contribute to the research literature by pointing out three implications. First, necessary condition analysis reveals that renewable energy consumption, real capital, labor force, and the rate of new firm formation are all necessary to some extent for economic development. To our knowledge, this study is the first using NCA to allow a more appropriate analysis of the hypothesized relationships. Second, this study focuses political attention on those necessary conditions that actually should be put in place or strengthened to achieve the desired higher level of economic growth. By contrast, while the French government has over-invested in renewable energy consumption, its efforts might be redirected to more important matters to achieve the desired outcome. Third, this study highlights a potential field for researchers in NCA methodology, which is of interest for applications concerning economic development and energy consumption. Furthermore, the methodology adopted in this study can be easily replicated.

In view of the above-mentioned results, the French government should continue to support the renewable energy sector by relying on different political tools. The policy to support renewable energies is based mainly on two levers, subsidies and tax benefits, as well as fossil energy taxation. In addition, the French government needs to define a coherent energy strategy balanced between the objectives of producing renewable electricity and reducing the role of nuclear energy in total energy consumption. As proposed by Eren et al. [40], there would be long-term benefits in considering the predominant use of nonrenewable energy, as well as encouraging new research and technological developments in renewable technologies. Therefore, France should invest in research and development (R&D), making it possible to meet the competitiveness challenges of renewable energies in the current context of energy markets, by developing legal and administrative authorization procedures to speed up the deployment of innovative projects.

The positive impact of new firm formation rate and economic growth means that the French government should sustain entrepreneurial activities [31]. According to this latter study, the necessity of entrepreneurship implies that there are sufficient prospects for significant growth. Policymakers should encourage small- and medium-sized (SMEs) enterprises to create innovation and employment to boost economic growth [21]. Furthermore, the French government should increase expenditure on R&D and education, while fostering an entrepreneurial culture, reducing the complexity of legal systems, and increasing public and private investment [27].

For further research, the concepts discussed here could be expanded to include other factors that could be necessary for economic growth. In addition, the NCA approach needs to be further developed and compared with conventional models, so it can then be used to provide new theoretical and practical insights.

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