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Determinants of Regional Consumption of Renewable Energies in France

Ferdaous Roussafi
Faculty of Economics and Management, Caen- Normandie University, France

Abstract: Energy transition tends to be at the heart of political and scientific agendas. However, this transition is carried out according to different rhythms and temporalities in line with the territories. It therefore seems essential to pay more attention to territorial dynamics in order to better understand the diversity of energy policy configurations and trajectories. In this context, we seek to study the factors that determine the regional consumption of renewable energies (RE) in France. We build a VECM model which explain the evolution of the share of RE in final energy consumption. The results indicate that in the short term, economic growth measured by the real GDP growth rate positively affects RE consumption, while nuclear and industrial production per capita have are a barrier to the promotion of RE. In the long term, estimates from the FM-OLS and DOLS models indicate that the log of GDP per capita, has a positive impact on the share of RE in final energy consumption. The results also show that research and development (R&D) expenditure favors the use of renewable energy. Finally, we show that at the regional level, the weight of "green" parties positively influences the development of RE.

Key words: renewable energy consumption, Panel co-integration, VECM model, FM-OLS and DOLS models, regional disparities

1. Introduction

In the context of efforts to combat climate change, RE has become an increasingly important source of energy, since the economic and social costs caused by traditional energy sources have led to questioning the sustainability of these resources. However, most of the energy demand is generally met by importing fossil fuels, accounting for almost 85.2% of global primary energy consumption in 2017. Nevertheless, this demand poses several problems, (i) increasing energy costs; (ii) population growth; (iii) increasing energy consumption per capita; and (iv) environmental problems. Therefore, it seems important to limit the use of fossil fuels and provide an opportunity for the expansion of the renewable energy (RE) sector [1, 2].

At the European level, RE offers states the opportunity to develop a competitive, reliable and sustainable energy sector. Besides, it contributes to solving the most urgent energy problems and challenges facing the community, particularly, reducing the energy dependence of countries on imports of fossil fuels such as oil, coal and natural gas [3], In addition, The European Union has set an overly ambitious target for reducing greenhouse gas emissions. By 2030, it aims to reduce them by 40% compared to the level recorded in 1990. To achieve this, it has established key objectives for this ambitious plan in October 2014. By 2030, more than 27% of its electricity production will have to come from RE sources, whereas RE accounted for only about 10% of the European Union's electricity production in 2015.

At the French level, RE is the fourth largest energy source after nuclear power, oil products and gas. Consequently, the country aims to reach 32% of RE in its gross consumption by 2030. To meet this ambitious target and diversify the country's energy mix, the French government has put different goals to be

Corresponding author: Ferdaous Roussafi, Ph.D.; research areas: energy transition and applied economics. E-mail: roussafiferdaous@gmail.com.

accomplished for each region, notably within the framework of the Regional Climate Air Energy Schemes.

Nowadays, RE investments are accelerating in many developed economies. The large energy potential and the high availability at national and local levels make renewable energy an important option with many advantages for states and regions [4]. However, many factors influence the use of these new energy sources. At the national level, the main determinants are energy prices, energy production, energy dependence, economic growth, trade openness and the volume of greenhouse gas emissions. In addition, countries' levels of development have a significant influence on the degree of interaction between these factors [5].

At the regional level, the study of the determinants of this consumption is a recent field of research. RE is spread all over France, but the different regions are not equal in the race to develop RE. Indeed, as a result of the differences in terms of potential, some regions have been forerunners and leaders in the development of RE. Comparing energy consumption or production between regions is not relevant to assess their respective performances. Indeed, the observed disparities reflect structural specificities of the economic structure, natural resources, or even differences in climate [6]. Thus, the understanding of the determinants of the differences in consumption or production is a key factor for the successful activation of the levers of energy policy at the local level.

Differences in population and density also help to explain the disparities in RE consumption from one region to another [7-9]. Similarly, the availability of fossil or natural resources and energy production potential affect the level of consumption. It is therefore interesting to analyze these indicators and understand their determinants in order to define the extent to which each region can contribute to the achievement of environmental objectives.

It then appears essential to take heed of territorial dynamics in order to better understand the elements that promote this consumption. Indeed, beyond geographical and climatic amenities, certain economic, environmental, demographic or political variables can explain the development of RE in a defined territory.

As part of the study of the determinants of RE consumption at the regional level, this paper aims to contribute to the literature on the determinants of RE consumption. We build an econometric model explaining the evolution of the share of RE in final energy consumption at regional level over the period 1990-2015. Our sample is made up of the 22 metropolitan regions and the French overseas departments (OD). Our analysis considers the heterogeneity of the regions by performing Granger causality tests of the vector error correction model (VECM) and panel causality tests. We also suggest a panel integration-cointegration analysis, using fully modified least squares (FMOLS) and dynamic least squares (DOLS) methods to estimate long-term effects.

This article is divided into three parts. The first section starts with a review of the literature. A second section is devoted to the presentation of data and methodology. The final section is dedicated to the presentation of the selected model, the interpretation of the empirical results and the resulting policy recommendations.

2. Literature Review

The empirical literature on the determinants of RE is relatively new. It has largely focused on the relationship between economic growth, nuclear energy consumption, RE consumption and CO_2 emissions. Works on the study of this causal link are a major area of interest within our field of research. However, most of the previous studies have only focused on cross-country comparisons; and research on regions are more limited or almost non-existent. The purpose of this article is precisely to remedy this shortcoming by proposing a contribution focusing on the French regions. We begin by outlining the main studies that have focused on the relationship between economic growth, nuclear energy consumption, RE consumption and CO_2 emissions.

Most of the studies of this causal link confirm the existence of a relationship between economic growth and RE consumption on the one hand, and between this variable and CO_2 emissions on the other hand. Increases in real GDP per capita and CO_2 emissions per capita seem to be the main drivers of renewable energy consumption, which in turn has a positive impact on economic growth.

N. Apergis, J. E. Payne (2011), H. A. Pao, H. C. Fu (2013), and M. Ben Jebli et al. (2014) [10-12] show the existence of bidirectional causality between RE consumption and real GDP per capita, while for N. Apergis and D. C. Danuletiu (2014) [13], the relationship is unidirectional from RE consumption to real GDP per capita. These results suggest that RE development is favorable to economic growth and that RE development policies cannot delay economic growth. The outcomes also confirm that economic growth is crucial to provide the resources needed for sustainable development. We assume that at the regional level, economic growth can also lead to an increase in RE consumption.

In addition, other results from K. Menyah and Y. Rufael (2010), and N. Apergis et al. (2010) [14, 15], indicate that short-term nuclear power consumption plays an important role in reducing CO_2 emissions, while M. Ben Jebli et al. (2014) [12] and M. Ben Jebli, S. Ben Youssef (2013) [16] showed a unidirectional causality from CO_2 emissions to RE consumption. In this context, A. K. Tiwari (2011) [17] confirms that a positive shock on RE consumption reduces CO_2 emissions. The results of the rest of the studies reveal that RE consumption does not contribute to the reduction of emissions. This can be explained by the lack of adequate storage technology to overcome the intermittency problems associated with the use of the new energy technologies, forcing power producers to rely on emissions-generating energy sources to meet demand.

T. Panayotou (1993) [18] and D. Stern (2004) [19] emphasized the impact of the economic structure on energy consumption (all sources taken together). Indeed, a strong sectoral specialization measured by a high degree of industrialization explains the contrasting levels of energy consumption between countries. Indeed, being polluting and very energy-intensive, industrial production has also been highlighted in many studies as a determining factor in energy consumption. In this perspective, Z. Wang, C. Shi, Q. Li and G. Wang (2011) [20] have shown that industrialization increases CO_2 emissions and energy consumption in China. At the regional level, we estimate that highly industrialized regions will tend to consume more energy from fossil or nuclear sources than from renewable sources.

Demographic factors are also determinants of RE consumption at the territorial level. However, there is no consensus on the effect of urbanization on RE development. Urbanization can degrade the quality of the environment. Rapid and uncontrolled urbanization increases the consumption of natural resources, generates pollution, which can favor the use of RE. S. Shafiei and R. A. Salim (2014) [21] analyzed the impact of urbanization on the consumption of renewable and non-renewable energy in OECD countries over the period 1980-2011. Their results show that urbanization has contributed to the total growth in energy consumption and to the growth in non-renewable energy consumption. They also found a significant negative relationship between population density and non-renewable energy consumption. J. Yang, W. Zhang, and Z. Zhang (2016) [22] showed that urbanization has a positive effect on the growth of RE consumption in China. As a result, the relationship between demographic variables and RE development at the regional level does not seem obvious. However, it is possible to speculate that energy solutions in an urban or rural area will be different. For example, wind and photovoltaic farms will be developed in rural areas.

I. Cadoret, F. Padovano (2016), A. C. Marques, J. A. Fuinhas, and J. Manso (2010), M. Dumas, J. Risingb, and J. Urpelainen (2016), M. Aklin, J. Urpelainen (2013) [23-26] introduce a political dimension in the analysis of the determinants of RE consumption. Indeed, I. Cadoret and F. Padovano (2016) [23] analyzed how political factors in the 26 EU countries affect the deployment of RE sources over the period 2004-2011. They compared the explanatory power of political factors with that of other economic, energy and environmental factors that have received more attention in the literature to date. The results of the estimation of the panel data show that manufacturing industry lobby delays the deployment of RE, while the quality of governance has a positive effect. Moreover, left-wing parties encourage RE deployment more than right-wing parties. A. C. Marques, J. A. Fuinhas, and J. Manso (2010) [24] also point out that lobbying from the hydrocarbon industries is a brake on RE deployment. We assume that at the regional level, the weight of “green” parties can influence the development of RE.

This political dimension was also analyzed by M. Dumas, J. Risingb, and J. Urpelainen (2016) [25], who presented a general dynamic model of renewable energy policy with a long-term horizon. The main characteristic of the model is the inclusion of technology learning and electoral competition between two political parties. The first party with “green” preferences and the other with “brown” preferences compete for authority and choose renewable energy policies. The results suggest that the most important effects of partisan ideology on policy occur when the conflicting parties disagree on the importance of energy policy. The authors also show that political dynamics could have important effects on RE development and carbon dioxide emissions over time, influencing the ability of countries to mitigate climate change.

In the same perspective, M. Aklin and J. Urpelainen (2013) [26] examined how exogenous shocks, such as changes in international energy prices, interact with positive reinforcing factors, like the growing strength of the RE coalition. Political competition affects policies to promote RE. Specifically, while “green” governments may use positive reinforcement mechanisms to lock in political commitments, “brown” governments do not promote public support for RE. The effect of positive reinforcement also decreases with international energy prices.

N. Kilinc-Ata (2015) [27] also studied the role of policy instruments to support RE, including feed-in tariffs, emission quotas, tender procedures and tax incentives, in promoting RE deployment in 27 EU countries and 50 US states for the period 1990-2008. The results suggest that adopted RE policies play an important role in the deployment of different sources of RE, but their effectiveness differs according to the type of instruments used. The upshots of the study indicate that feed-in tariffs, tender procedures and tax incentives are effective mechanisms to stimulate the deployment capacity of RE sources for electricity, in contrast to emission quotas policies.

3. Methodological Approach and Data

3.1 Data Presentation and Preliminary Analysis

In this section we describe the data. Then, we present a brief description of the French regional characteristics of the selected variables and the statistical properties of the series.

Based on the literature review, we selected the following variables to explain the share of RE consumption in total energy consumption: (SREC.TFEC):

- GDP per capita in value (GDP.cap),
- The GDP growth rate (GR_GDP),
- R&D expenditure per capita (RDE.cap),
- Industrial production per capita (IP.cap),
- Per capita GHG emissions (GHGE.cap),
- -Nuclear electricity production per capita (NEP.cap),
- Regional population density (DENS),

- The urbanization rate (UR), and
- The score of environmentalist parties in regional elections (SEP).

The sample is a cylindrical panel of 598 observations, relating to the 23 French regions observed over the period 1990-2015. The use of panel data econometrics has a great advantage. Indeed, the panel data have two dimensions, temporal and individual, favoring a simultaneous study of the dynamics and heterogeneity of the regions' behavior.

The descriptive statistics of the data are presented in Table 1, while their variances are reported in Table 2.

We note that our sample shows a high degree of heterogeneity in the variables. In particular, the share of RE in final energy consumption varies strongly from 1.04% in Ile-de-France (IDF), in 1998 to 60.34% in the Limousin, in 2015. This heterogeneity is also marked at the regional level. Indeed, on average, Limousin is at the top of the ranking of regions in terms of RE consumption over the period 1990-2015, while Ile-de-France ranks last. GDP per capita, which averages 22,806.05 €, also varies widely between 9,721 € in the OD and 54,646 € in IDF.

Table 1 Descriptive statistics.

Series	Mean	standard deviation	Min	Max	number of observations
SREC.TFEC	0.1053	0.088	0.01	0.6034	598
GDP.cap	22806	6178	9721	54646	598
GR_GDP	0.024	0.021	-0.055	0.075	598
RDE.cap	335.43	240.9	20	1462	598
IP.cap	0.0047	0.001	0.002	0.0072	598
GHGE.cap	0.1759	0.787	0.002	4.67	598
NEP.cap	0.0068	0.011	0	0.121	598
Dens	132.53	183.3	16	1001	598
UR	0.6881	0.142	0.163	1	598
SEP	0.0755	0.055	0	0.2127	598

Table 2 Total, within and between variances.

Series	Overall	Between	Within.
SREC.TFEC	0.007	0.002	0.005
GDP.cap	0.012	0.006	0.006
GR-GDP	0.001	0.001	0
Log-RDE	0.113	0.08	0.033
LOG-IP	0.017	0.013	0.004
NEP.cap	0.011	0.011	0
LOG-GHGE.	0.772	0.449	0.323
UR	35073	34992	81
DENS	0.021	0.017	0.004
SEP	0.064	0.062	0.002

For the other series, we find the same characteristic, i.e., a great diversity of situations among the regions in the sample. For example, for the research and development expenditure per capita series, the values vary between 20 € per capita in Corsica and 1462 € per capita in the Midi-Pyrénées. The population density series also shows great variability, ranging from 16 inhabitants per km² in the OD to 1001 inhabitants per km² in IDF.

Within the framework of the study of the statistical properties of the series, it is possible to perform an intra-individual and inter-individual variance calculation before carrying out linear panel regressions. In fact, the method of estimating a panel model is based on the use of variability components (variance). Thus, the decomposition of the total variance of each series into two orthogonal sub-variances: inter-individual (or inter, also called between) and individual (or intra, also called within), gives us an indication of the dominant variability. This decomposition is written as follows:

$$Var_{tot} = Var_{within} + Var_{between}$$

The inter-individual variance (between) of the dependent variable is equal to 0.002 while the intra-individual variance (Within) is equal to 0.005 for a total variance of 0.007. In other words, the inter-individual and intra-individual variances represent respectively 29 and 71% of the total variance. This is explained by the large difference between the values observed from one year to another for the same region compared to the variability and interactions between regions. This decomposition is the same for "Log_ RDE" and "GR_GDP". For the rest of the variables, the differences between regions are greater than the differences observed over the entire period for the same region.

All level variables including GDP per capita by value [1], R&D expenditure per capita, Industrial production per capita and GHG emissions per capita, will be introduced into the econometric analysis in a logarithmic form. The use of log series not only allows the series to be smoothed, but also allows the model coefficients to be estimated and interpreted in terms of elasticity. The variables considered are as follows:

- GDP per capita in value (GDP.cap),
- The GDP growth rate (GR_GDP),
- R&D expenditure per capita (log_RDE),
- Industrial production per capita (log_IP),
- Per capita GHG emissions (log_GHGE),
- Nuclear electricity production per capita (log_NEP),
- Regional population density (DENS),
- The urbanization rate (UR), and
- The score of environmentalist parties in regional elections (SEP)

3.2 Series Properties

In the first step of our empirical analysis, it is crucial to determine the statistical properties of the series. Most of the economic variables, including GDP.hab, RDE.cap and IP.cap show an increasing trend over time. Therefore, it is important to distinguish between a stationary process with a deterministic trend and a process with a stochastic trend or unit root. The study of stationarity is carried out using unit root tests. A serie that does not have a unit root fluctuates around a constant long-term average. Therefore, shocks have only a temporary effect. On the other hand, if a series has a unit root, it is preferable to characterize it as a non-stationary process that does not follow a deterministic path in the long run and whose shocks have permanent effects on the value of the process [28].

If the series follow a stationary process with a deterministic trend, stationarity is obtained by eliminating the time trend. If the series has a stochastic trend or a unit root, stationarity is obtained by differentiating the series. Finally, the study of the properties of series requires information on the presence or absence of unit roots; regression models applied to non-stationary variables lead to erroneous results unless the variables are integrated.

The properties of the series are evaluated in the context of panel data. The two-dimensional nature of panel data enables us to solve a difficulty associated to time series: the low power of unit root and cointegration tests on small samples. Indeed, adding the cross-sectional dimension (French regions) to the time dimension solves this problem by increasing the number of observations. Finally, one of the advantages of unit root tests in panel data is that their asymptotic distribution is normal, unlike those performed in time series, which have non-standard asymptotic distributions [29].

First, we implemented the tests of Levin and Chien-Fu (1992) [30], Harris-Tzavalis (1999) [31] and Breitung (2001) [32] based on the null hypothesis of a common unit root process. However, the homogeneity of the autoregressive root under the alternative hypothesis seems very restrictive. Indeed, in these tests, heterogeneity consists in postulating the existence of specific individual constants. This is of course the individual effects model (specified in a fixed or random

[1] Except for nuclear electricity production per capita since it contains zero values for some regions.

way), which reflects heterogeneity only at the mean level. The hypothesis of homogeneity of the other parameters of the model and the autoregressive root is thus retained. Therefore, we also developed the tests of Im et al. (2003) [33] and Hadri (2000) [34], which allow under the alternative hypothesis a heterogeneity of the autoregressive root.

We implemented several unit roots tests under the hypothesis of cross-sectional independence. Under the alternative hypothesis, some series may be characterized by a unit root, while other series may be stationary. The tests of Levin, Lin and Chu (LLC), Breitung, Harris-Tzavalis (H-T) and Im, Pesaran and Shin (IPS) are based on the null hypothesis of unit root, while Hadri's test is based on the null hypothesis of stationarity. The results of these different tests, presented in Table 3, are concordant for all four tests (LLC, Breitung, H-T and IPS), except for the variables: Log_GDP, Log_RDE and NEP.cap. For a 1% risk of error, the unit root hypothesis is often rejected when the series are in level except for the variables SREC.TFEC, Log_IP, DENS, Log_GDP (except for the LLC and IPS tests), Log_RDE (except for the Breitung, H-T and IPS tests) and PEN (except for the LLC test) while it is systematically rejected when the series are in first differences. All the variables are therefore stationary in first difference.

Table 3 Panel unit root tests (first generation).

Variables	LLC	Breitung	H-T	IPS	Hadri
			Variables: Level		
SREC.TFEC	10.02	7.3	1.11	14.32	40.94***
Log_GDP	-6.25 ***	12.29	0.96	-1.97 ***	73.67***
GR_GDP	-8.04 ***	-5.86 ***	0.21***	-10.57 ***	10.88***
Log_RDE	-2.45 ***	10.49	0.94	2.99	69.74 ***
Log_IP	-0.98	4.82	0.97	3.01	65.94 ***
NEP.cap	2.11	-5.17 ***	0.04***		3.67 ***
Log_GHGE	-3.48 ***	-2.12 ***	0.13***	-7.67 ***	8.26 ***
UR	-39.22 ***	-5.46 ***	0.24***	-8.75 ***	12.5 ***
DENS	2.42	11.96	1.01	6.68	74.92 ***
SEP	-3.46 ***	-5.45 ***	0.68***	-3.49 ***	7.79 ***
			Variables: First Difference		
SREC.TFEC	-4.22 ***	-10.8 ***	0.30***	-8.98 ***	18.51 ***
Log_GDP	-9 ***	-11.49 ***	0.20***	-9.52 ***	7.95 ***
GR_GDP	-17.76 ***	-11.84 ***	-0.34***	-15.44 ***	-4.16
Log_RDE	-106 ***	-13.01 ***	-0.33***	-13.09 ***	-3.62
Log_IP	-12.87 ***	-12.12 ***	0.12***	-11.09 ***	1.35 ***
NEP.cap	-2.52 ***	-5.17 ***	-0.50***		-4.67
Log_GHGE	-12.86 ***	-2.12 ***	-0.48***	-15.41 ***	-4.6
UR	-93.44 ***	-4.58 ***	-0.46***	-18.16 ***	-4.39
DENS	-8.68 ***	-11.11 ***	- 0.25***	-13.63 ***	8.74 ***
SEP	-8.81 ***	-15.45 ***	-0.002***	-10.97 ***	-1.16

*** The rejection of the null hypothesis at the 1 % level

According to the first four tests, the variables SREC.TFEC, Log_IP, DENS are integrated of order 1 (I (1)), whereas the variables GR_GDP, Log_ GHGE, UR and SEP are stationary. Finally, in Hadri's test, the null hypothesis of stationarity is always rejected for a 1% risk of error, whether for level or first difference series (except for first difference series: GR_GDP, NEP.cap, Log_ GHGE, UR and SEP).

Beyond their diversity, these first-generation tests face a major problem: the problem of inter-individual independence (independence of residues in Levin and Lin, or in IPS). As a result, many empirical studies [35, 36] assuming the cross-sectional independence of deviations of GDP per capita from the international average have been confronted with this problem despite the introduction of time effects to capture the effects of the international economic cycle. To test the cross-sectional dependence of each variable, we will use the Pesaran (2004) [37] test (Table 4). The null hypothesis H0 is the cross-sectional independence. Pesaran's CD statistic is based on the average of the correlation coefficients between the different regions taken two by two for each year. Under the null hypothesis, this statistic is asymptotically distributed according to a reduced centered normal distribution. The mean of the coefficients is indicated by Moy. ρ and the mean of the absolute value of the correlation coefficients by Moy $|\rho|$.

Table 4 clearly indicates the presence of strong cross-sectional dependence for all variables for all regions.

Table 4 Pesaran 2004 cross-section dependency test.

	SREC.TFEC	Log_GDP	GR_GDP	Log_RDE	Log_IP	Log_GHGE	UR	DENS	SEP
CD-test	61.346	80.329	54.676	74.279	70.866	9.786	15.655	67.203	52.941
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Mean.ρ	0.76	0.99	0.67	0.92	0.87	0.12	0.19	0.83	0.65
Mean. |ρ|	0.76	0.99	0.67	0.92	0.87	0.54	0.60	0.86	0.74

We therefore considered unit-root tests that consider cross-sectional dependence, called second-generation tests. We applied the tests of Pesaran (2007) [38] and Pesaran (2003) [39] based on the null hypothesis of the unit root for all units and a heterogeneous alternative hypothesis. In both tests, an unobserved common factor structure is assumed to explain the cross-sectional correlation. Pesaran's (2007) tests of transversally augmented unit root are designed for cases where the cross-sectional dependence is due to a single factor. Cross-sectional dependence is accounted for by increasing individual Dickey-Fuller regressions augmented by the cross-sectional mean of the dependent variable. These cross-sectional means are used as proxies for the single common factor assumed to be unobserved. The test statistic proposed by Pesaran, called CIPS, is then based on the mean of the individual cross-sectional unit statistics. For this test, the null hypothesis H0 is that each individual time series contains a unit root. The alternative hypothesis is that some of the series are stationary. The values reported in Tables 5 and 6 correspond to the CIPS test statistic (Z t-bar) for all variables in the model. The test is performed in the case where a constant, specific to each region, and a linear trend are added to the model.

From Tables 5 and 6, we can deduce that the variables SREC.TFEC, Log_GDP, Log_IP, UR and SPE are not stationary in level but stationary in first differences. They are therefore first-order integrated. The NEP.cap series is not stationary either in level or in first difference. For the rest of the variables (GR_GDP, Log_RDE, Log_ GHGE, DENS), the null hypothesis of unit root is systematically rejected at the 1% level for the level and first difference series.

Pesaran (2003) suggests a single test to consider possible dependencies between individuals. He chooses to keep the raw series by increasing the DF or ADF model by introducing individual means and first differences: we then obtain a Cross Sectionally Augmented Dickey-Fuller (CADF) type augmented model. On the contrary, he chooses to keep the raw series by increasing the DF or ADF model by introducing individual means and first differences: we then obtain a Cross Sectionally Augmented

Dickey-Fuller (CADF) type augmented model. From this point of view, Pesaran's (2003) test differs from the tests previously presented. In fact, the asymptotic distributions are non-standard.

The results of this test (Table 7) lead us, for a 1% risk of error, to reject the null hypothesis of a unit root for the variables; SREC.TFEC, Log_GDP, GR_GDP, Log_RDE, UR and DENS. The variables Log_IP, Log_GHGE and SEP are not stationary in level but stationary in first differences, they are thus first-order integrated. The PEN series are not stationary either in level or in first difference.

Table 5 Pesaran Unit Root Test (2007) (level variables).

					Constant					
Lag	**SREC.TFEC**	**Log_GDP**	**GR_GDP**	**Log_RDE**	**Log_IP**	**NEP.cap**	**Log_GHGE**	**UR**	**DENS**	**SEP**
1	-1.9	-2.7***	-4.6***	-2.7***	-1.5	-0.5	-2.7***	-0.5	-2.9***	-1.4
2	-2.3***	-2.7***	-4.6***	-2.5***	-1.5	-0.5	-2.7***	-0.7	-2.9***	-1.4
3	-2.0***	-2.9***	-4.7***	-2.5***	-1.6	-0.5	-2.8***	-0.6	-2.9***	-1.5
					Linear trend					
Lag	**SREC.TFEC**	**Log_GDP**	**GR_GDP**	**Log_RDE**	**Log_IP**	**NEP.cap**	**Log_GHGE**	**UR**	**DENS**	**SEP**
1	-2.6	-2.4	-4.6***	-3.1***	-1.8	-1.2	-3.1***	-2.4	-3.1 ***	-1.6
2	-2.9***	-2.4	-4.5***	-3.0***	-1.8	-1.2	-3.1***	-2.6	-3.0***	-1.6
3	-2.8***	-2.6	-4.5***	-3.1***	-1.8	-1.2	-3.2***	-2.6	-3.1***	-1.6

Table 6 Pesaran unit root test (2007) (first difference variables)

Lag	**Δ SREC.TFEC**	**Δ Log_GDP**	**Δ GR_GDP**	**Δ Log_RDE**	**Constante** **Δ Log_IP**	**Δ NEP.cap**	**Δ Log_GHGE**	**Δ UR**	**Δ DENS**	**Δ SEP**
1	-4.8***	-4.6***	-6.1***	-5.7***	-4.6***	-1.5	-4.7***	-5.7***	-5.5***	-3.7***
2	-4.8***	-4.5***	-6.1***	-5.6***	-4.7***	-1.5	-4.7***	-5.8***	-5.6***	-3.8***
3	-4.9***	-4.7***	-6.0***	-5.7***	-4.6***	-1.5	-4.7***	-5.8***	-5.6***	-3.8***
Lag	**Δ SREC.TFEC**	**Δ Log_GDP**	**Δ GR_GDP**	**Δ Log_RDE**	**Linear** **Δ Log_IP**	**Trend** **Δ NEP.cap**	**Δ Log_GHGE**	**Δ UR**	**Δ DENS**	**Δ SEP**
1	-4.9***	-4.6***	-6.2***	-5.8***	-4.8***	-2.1	-4.9***	-6.0***	-5.9***	-3.9***
2	-5.0***	-4.5***	-6.2***	-5.8***	-4.8***	-2.0	-4.9***	-6.0***	-5.9***	-3.9***
3	-5.1***	-4.6***	-6.1***	-5.7***	-4.9***	-2.1	-4.9***	-6.1***	-5.8***	-4.0***

Table 7 Pesaran Unit Root Test (2003).

Variables	**CADF**	
	Variables: level	*Variables: first difference*
SREC.TFEC	-2.04*	-3.71***
Log_GDP	-2.46***	-3.13***
GR_GDP	-3.16***	-4.78***
Log_RDE	-2.34***	-3.80***
Log_IP	-1.61	-3.32***
NEP.cap	0.11	-0.90
Log_GHGE	-1.97	-3.05***
UR	-4.41***	-5.34***
DENS	-2.47***	-3.89***
SEP	-1.74	-2.84***

Finally, our results show that under the hypothesis of cross-sectional independence, several series are stationary, while for others the unit root hypothesis is accepted. Second generation tests that consider cross-sectional dependence confirm this result. However, all variables are stationary in first differences, which justifies the analysis of cointegration, whose presence will be tested later.

4. Results and Discussion

4.1 Long-Term Analysis

In this section, we use panel data cointegration tests between the model variables. Recall that to avoid spurious regressions, variables must be cointegrated [40-42]. Cointegrated data series may evolve separately in the short run, but there are forces that cause them to evolve together in the long run. On the other hand, the absence of cointegration suggests that the variables are not related in the long run.

To understand the long-term relationships between the share of RE in final energy consumption and the explanatory variables, we implement bivariate cointegration tests in both regional time series and panel data. The study of cointegration in regional time series allows the identification of long-term relationships between the two series at the regional level. While the study of cointegration in panel data provides comprehensive information at the national level. Moreover, since cointegration tests suffer from low power over small samples as in the case of unit root tests, adding the individual dimension to the usual time dimension increases the power of cointegration tests.

As in the case of the first-generation unit root panel tests, the distinction between the different cointegration tests depends on whether there is heterogeneity in the panel. We consider the tests proposed by Pedroni (2004) [43], Kao (1999) [44], and Westerlund (2007) [45]. Pedroni proposed tests based on the null hypothesis of the absence of intra-individual cointegration for heterogeneous panels. From the seven tests proposed by Pedroni, four are based on the within (intra) dimension and three on the between (inter) dimension. Both categories of tests are based on the null hypothesis of the absence of cointegration. Kao's test is also based on the null hypothesis of the absence of cointegration and assumes the homogeneity of the cointegration vectors in the individual dimension. Westerlund (2007) suggested a cointegration test based on structural dynamics rather than on residual dynamics and therefore imposes no restrictions on common factors. The idea is to test the null hypothesis of no cointegration by testing the significance of the error-correction term in a conditional error-correction model.

The three tests presented in Table 8 lead us to reject the non-cointegration hypothesis and conclude that there is a cointegrating relationship between the share of RE in final energy consumption and all the explanatory variables.

Table 8 Cointegration panel tests.

Variables	Pedroni						Kao	Westerlund
	Tests based on the within-dimension			Tests based on the between- dimension				
	Rho-stat	PP-stat	ADF-stat	Rho-stat	PP-stat	ADF-stat	t-stat	Variance ratio
SREC.TFEC/Log_GDP	5.40 (0.00)	8.30 (0.00)	11.97 (0.00)	4.13 (0.00)	6.41 (0.00)	8.79 (0.00)	2.48 (0.006)	-1.91 (0.02)
SREC.TFEC/GR_GDP	5.38 (0.00)	8.57 (0.00)	8.46 (0.00)	3.75 (0.0001)	5.94 (0.00)	5.62 (0.00)	4.91 (0.00)	1.60 (0.05)
SREC.TFEC/Log_RDE	4.83 (0.00)	6.84 (0.00)	9.25 (0.00)	3.07 (0.00)	4.35 (0.00)	5.95 (0.00)	2.89 (0.001)	-1.66 (0.04)
SREC.TFEC/Log_IP	5.31 (0.00)	8.15 (0.00)	10.49 (0.00)	3.82 (0.00)	5.84 (0.00)	7.32 (0.00)	2.66 (0.003)	-1.35 (0.08)
SREC.TFEC/NEP.cap	4.02 (1.00)	6.94 (1.00)	5.43 (1.00)	3.97 (1.00)	7.21 (1.00)	6.84 (1.00)	4.65(0.00)	3.14 (0.0008)
SREC.TFEC/Log_GHGE	6.05 (0.00)	10.7 (0.00)	10.62 (0.00)	4.90 (0.00)	8.00 (0.00)	7.61 (0.00)	5.11 (0.00)	1.79 (0.03)
SREC.TFEC/UR	5.83 (0.00)	10.65 (0.00)	11.22 (0.00)	4.83 (0.00)	7.81 (0.00)	8.23 (0.00)	5.14 (0.00)	2.32 (0.01)
SREC.TFEC/DENS	4.16 (0.00)	5.72 (0.00)	7.79 (0.00)	2.79 (0.002)	4.00 (0.00)	5.51 (0.00)	4.78 (0.00)	-2.15 (0.01)
SREC.TFEC/SEP	6.70 (0.00)	14.30 (0.00)	15.28 (0.00)	6.05 (0.00)	10.93 (0.00)	11.50 (0.00)	6.92 (0.00)	3.33 (0.0004)

Although OLS estimators of cointegration vectors are super-convergent, their distribution is asymptotically biased and depends on nuisance parameters associated with the presence of serial correlation in the data [46, 47]. Such problems are present in the traditional univariate temporal case, also arise for panel data and tend to be even more pronounced in the presence of heterogeneity.

To estimate systems of cointegrated variables, as well as to perform tests on cointegrating vectors, it is therefore necessary to use an efficient estimation method. Various techniques can be used, such as the FM-OLS (Fully Modified Ordinary Least Squares) method originally proposed by Phillips and Hansen (1990) [48] or the Dynamic Ordinary Least Squares (DOLS) method of Saikkonen (1991) [49]. In the case of panel data, Kao and Chiang (2000) [50] have shown that these two techniques lead to asymptotically distributed estimators with a normal distribution. Similar results are obtained by Phillips and Moon (1997) [51] for the FM-OLS method.

In conclusion, Kao and Chiang (2000) [50] investigated the properties of OLS, FM-OLS and DOLS estimators. Their study points out that the OLS estimator suffers from a large bias problem and that the FM-OLS estimator does not substantially improve the OLS estimator. They then conclude that the DOLS estimator is superior for the estimation of panel cointegration relationships.

For the two estimators FM-OLS and DOLS, the long-term relationship can be formulated by the following equation:

$$\begin{aligned} \text{SREC.TFEC}_{i,t} &= \alpha_i + \beta_i \text{Log\_GDP}_{i,t} + \gamma_i \text{GR\_GDP}_{i,t} + \delta_i \text{LOG\_RDE}_{i,t} + \theta_i \text{Log\_IP}_{i,t} + \lambda_i \text{NEP.cap}_{i,t-2} + \varphi_i \text{Log\_GHGE}_{i,t-2} \\ &+ \partial_i \text{UR}_{i,t} + \omega_i \text{DENS}_{i,t} + \vartheta_i \text{SEP}_{i,t-1} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

Where i, t, ∝i and εi, correspond respectively to region, time, regional fixed effect and error term.

βi, δi, θi and φi are respectively the GDP, R&D expenditure, industrial production and greenhouse gas emissions elasticities of renewable energy.

Finally, γi, λi, ∂i, ω_i and ϑi correspond to the coefficients of the variables: GDP growth rate, nuclear electricity production, urbanization rate, density and score of environmental parties.

In addition, some variables, such as greenhouse gas emissions and nuclear power generation per capita and the score of environmental parties are introduced into the model with lags since their effect on the share of RE consumption is not assumed to be immediate. We tested several lags structures, the most optimal is the one presented in Eq. (1).

In line with the results of N. Apergis and J. E. Payne (2011) [10], P. Sadorsky (2009) [2], and M. Ben Jebli, S. Ben Youssef, I. Ozturk [12], estimates of long-term relationships (Table 9) between regional time series indicate that the level of development of the economy, measured by the log of GDP per capita, significantly explains the share of RE in final energy consumption. A 1% increase in GDP per capita increases the share of RE consumption by 0.66%. It may be concluded that sustained high economic growth stimulates the energy transition by encouraging the consumption of alternative energies that can partially compensate for the depletion of fossil resources. This result argues in favor of government policies for the development of the RE sector and can provide valuable information for policy makers. Indeed, sustained economic development means greater potential to support high regulatory costs and more resources available to implement and promote the use of RE.

The results also indicate that the volume of research and development expenditure has a positive effect on the share of RE consumption. A 1% increase in R&D expenditure per capita increases the share of RE consumption by 0.232%. Public research and development (R&D) expenditure on renewable energies will amount to 126 million euro in 2017, i.e., nearly 13% of total public R&D expenditure for energy (973 million euro in 2017). This expenditure is mainly concentrated in two sectors: solar energy (43% of expenditure, i.e., 55 million euro) and biomass (41%, i.e., 52 m million euro). In the case of biomass, the expenditure concerns mainly biofuels and biogas. Increasing investment in renewable energy research and development is therefore capable of increasing the competitiveness of these energies and remedying the main technological challenges they face, notably intermittency and storage problems. Consequently, in the long term, this action will make it possible to increase the share of renewable energy in total energy consumption.

Table 9 Panel DOLS and FM-OLS estimates.

Variables	DOLS		FMOLS	
	Coefficient	t-stat.	Coefficient	t-stat.
Log_GDP	0.66(0.101)*	1.22	1.04 (0.10)*	1.6
GR_GDP	0.81 (0.446)	0.98	0.31 (0.444)	0.76
Log_RDE	0.232 (0.07)*	1.80	0.25 (0.08) *	1.74
LOG_IP	0.59 (0.254)	1.14	1.13 (0.05) **	1.90
NEP.cap (-2)	0.84 (0.458)	0.74	0.15 (0.886)	0.14
LOG_GHGE (-2)	-0.09(0.375)	-0.88	-0.07 (0.474)	-0.71
UR	0.042(0.810)	0.24	0.11 (0.568)	0.57
DENS	0.01 (0.002) ***	3.08	0.01 (0.003) ***	2.9
SEP (-1)	0.85(0.000) ***	5.28	0.83 (0.0001) ***	4.12
R^2	**0.51**		**0.59**	

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ and the numbers in brackets indicate probability values.

On the other hand, the impact of the structure of the economy, especially industrialization, on the environment was also highlighted as a factor explaining RE consumption. Estimates from the FM-OLS model confirm the positive effect of industrial production on the share of RE in final RE consumption. In the long term, industrialized regions will tend to deviate from the usual energy trends (fossil and nuclear) and consume more RE in order to diversify their energy mix.

The results also show that there is a statistically highly significant positive relationship between the score of environmental parties and renewable energy consumption. At the regional level, the weight of "green" parties has a positive influence on the development of RE. The score of the green parties reflects the orientation of the region towards environmental issues and tells us about the degree of commitment of voters to the environmental cause. At the national level, this result was highlighted by M. Dumas, J. Risingb, J. Urpelainen (2016) [25] and M. Aklin, J. Urpelainen (2013) [26]. These authors have shown that "green" governments promote public support for RE. H. Karlstrøm and M. Ryghaug (2014) [52] also found that the preference for green political parties has an important impact on attitudes towards energy technologies in Norway.

Finally, the results also show a significant positive effect of population density on RE consumption. In contrast to S. Shafiei and R. A. Salim (2014) [21], we show that RE consumption in France is explained by population density. Thus, increased population density leads to an increase in renewable energy consumption since a region's energy demand depends on its population's lifestyle.

4.2 Short-Term Analysis

4.2.1 Vector Error Correction Model (VECM) Estimates

In time series, it is common to distinguish between short-term and long-term analyses. While long-term effects are important for the implementation of RE development policies, short-term analysis provides useful information to identify interactions between variables and dynamic adjustments. The use of causality tests allows us to reveal the direction of the existing relationships between variables.

The presence of a cointegrating relationship makes it possible to use a VECM (vector error correction model) representation. The VECM is a model that allows us to model the adjustments that lead to a long-term equilibrium situation. We use the approach of N. Apergis et al. (2010) [15] to analyze short-term relationships between regional time series. From a strictly technical point of view, the number of parameters to be estimated in this model increases with the number of lags. The values of the AIC criterion lead us to retain two lags.

The basic writing of the VECM model is given below:

$$\Delta\mathbf{SREC.TFEC}_t = \propto_{10} + \sum_{i=1}^{2} \propto_{1i} \Delta\text{SREC.TFEC}_{t-i} + \sum_{i=1}^{2} \beta_{1i} \Delta\text{Log\_GDP}_{t-i} + \sum_{i=1}^{2} \gamma_{1i} \Delta\text{GR\_GDP}_{t-i} + \sum_{i=1}^{2} \theta_{1i} \Delta\text{Log\_RDE}_{t-i} + \sum_{i=1}^{2} \vartheta_{1i} \Delta\text{Log\_IP}_{t-i} + \sum_{i=1}^{2} \mu_{1i} \Delta\text{NEP.cap}_{t-i} + \sum_{i=1}^{2} \pi_{1i} \Delta\text{Log\_GHGE}_{t-i} + \sum_{i=1}^{2} \sigma_{1i} \Delta\text{UR}_{t-i} + \sum_{i=1}^{2} \tau_{1i} \Delta\text{DENS}_{t-i} + \sum_{i=1}^{2} \omega_{1i} \Delta\text{SEP}_{t-i} + \varphi_1\text{SREC.TFEC}_{t-1} + \varphi_2\text{Log\_GDP}_{t-1} + \varphi_3\text{GR\_GD}_{t-1} + \varphi_4\text{Log\_RDE}_{t-1} + \varphi_5\text{Log\_IP}_{t-1} + \varphi_6\text{NEP.cap}_{t-1} + \varphi_7\text{Log\_GHGE}_{t-1} + \varphi_8\text{UR}_{t-1} + \varphi_9\text{DENS}_{t-1} + \varphi_{10}\text{SEP}_{t-1} + \varepsilon_{1t}$$

In detail, the model is written as follows:

$$\Delta\mathbf{SREC.TFEC}_t = \text{C}_{22} + \text{C}_1 * (\varphi_0 + \varphi_1\text{SREC.TFEC}_{t-1} + \varphi_2\text{Log}_{\text{GDP}_{t-1}} + \varphi_3\text{GR}_{\text{GD}_{t-1}} + \varphi_4\text{Log}_{\text{RDE}_{t-1}} + \varphi_5\text{Log}_{\text{IP}_{t-1}} + \varphi_6\text{NEP.cap}_{t-1} + \varphi_7\text{Log}_{\text{GHGE}_{t-1}} + \varphi_8\text{UR}_{t-1} + \varphi_9\text{DENS}_{t-1} + \varphi_{10}\text{SEP}_{t-1}) + C_2\Delta\text{SREC.TFEC}_{t-1} + C_3\Delta\text{SREC.TFEC}_{t-2} C_4\Delta\text{Log}_{\text{GDP}_{t-1}} + C_5\Delta\text{Log}_{\text{GDP}_{t-2}} + C_6\Delta\text{GR}_{\text{GDP}_{t-1}} + C_7\Delta\text{GR}_{\text{GDP}_{t-2}} + C_8\Delta\text{Log}_{\text{RDE}_{t-1}} + C_9\Delta\text{Log}_{\text{RDE}_{t-2}} + C_{10}\Delta\text{Log}_{\text{IP}_{t-1}} + C_{11}\Delta\text{Log}_{\text{IP}_{t-2}} + C_{12}\Delta\text{NEP.cap}_{t-1} + C_{13}\Delta\text{NEP.cap}_{t-2+}C_{14}\Delta\text{Log}_{\text{GHGE}_{t-1}} + C_{15}\Delta\text{Log}_{\text{GHGE}_{t-2}} + C_{16}\Delta\text{UR}_{t-1} + +C_{17}\Delta\text{UR}_{t-2} + C_{18}\Delta\text{DENS}_{t-1} + C_{19}\Delta\text{DENS}_{t-2} + C_{20}\Delta\text{SEP}_{t-1} + C_{21}\Delta\text{SEP}_{t-2} + \varepsilon_{1t}$$

Estimates (Table 10) indicate that the share of RE consumption of renewable energy depends on its past values ((t-1) and (t-2)). Real GDP per capita which reflects the level of economic development of the region, has a positive impact on renewable energy consumption. The results also show that the level of economic growth in the past period measured by the real GDP growth rate positively affects RE consumption. In the short term, a strong economic growth favors the use of RE sources. While it seems clear that economic growth is accompanied by a significant increase in energy demand, the development of RE must be at the center of public policy concerns and mobilize sustained investment efforts. The results also show that nuclear and industrial production per capita have a negative impact on RE consumption. In the short term, nuclear energy seems to be an obstacle to the promotion of RE. Regions where nuclear is the predominant energy source will tend to consume less RE in their energy mix.

Table 10 Result of the estimation of the VECM model.

	Coefficient	Std.Error	t-Statistic	Prob
C(1)	0.0003	0.001	0.304	0.760
C(2)	0.234	0.044	5.327	0.000
C(3)	0.197	0.044	4.473	0.000
C(4)	3.264	1.039	3.141	0.002
C(5)	1.754	1.052	1.667	0.095
C(6)	0.916	0.450	2.034	0.041
C(7)	0.092	0.045	2.057	0.039
C(8)	-0.002	0.020	-0.103	0.917
C(9)	0.002	0.018	0.128	0.897
C(10)	-0.136	0.075	-1.813	0.069
C(11)	-0.008	0.076	-0.105	0.916
C(12)	-0.339	0.138	-2.454	0.014
C(13)	0.118	0.138	0.856	0.391
C(14)	0.001	0.009	0.177	0.859
C(15)	-0.006	0.009	-0.729	0.465
C(16)	-0.021	0.017	-1.176	0.239
C(17)	-0.017	0.013	-1.243	0.213
C(18)	-0.001	0.001	-1.067	0.285
C(19)	0.002	0.001	1.509	0.131
C(20)	0.015	0.027	0.577	0.563
C(21)	0.009	0.026	0.357	0.721
C(22)	0.0179	0.015	1.170	0.241

4.2.2 Causality Tests

In order to analyze the short-term relationships between the share of RE in final energy consumption and other variables, we conducted Granger non-causality tests in a bivariate framework on regional time series and panel causality tests.

a) Granger Causality Tests on Regional Time Series

The causal relationship between the explanatory variables and the share of RE in final energy consumption was investigated using the Granger causality analysis of the vector error correction model. The causality test gives us the direction of causality but not the sign. We focus our analysis on the unidirectional causality links between the explanatory variables and the endogenous variable, as we are mainly interested in the effect of these variables on the share of RE in final energy consumption.

Our results, presented in Table A1 (appendix), indicate that there is a unidirectional causality running from economic growth (Log_GDP) to RE consumption (Share of RE) in Auvergne, Bretagne, Champagne-Ardenne, Franche-Comté, Ile-de-France, Midi-Pyrénées, Pays de la Loire and Picardie. An increase in GDP may lead to an increase in RE consumption in these regions. Economic growth in these regions — among others — leads to new opportunities to promote renewable energy. In this case, it could be deduced that for these regions, RE consumption is sensitive to the economic situation of the region. A bidirectional relationship between these two variables appears in Basse-Normandie and Poitou-Charentes. RE consumption can positively affect economic growth, which in turn favors the use of RE sources.

Another causal link is also found between the volume of R&D expenditure and our dependent variable. Indeed, for the regions, Basse-Normandie, Franche-Comté, Midi-Pyrénées and Poitou-Charentes, the unidirectional causality goes from Log_DRD to SREC.TFEC. Indeed, research and development programs are the oldest form of support for renewable energy deployment. They aim to improve the performance of renewable energy technologies that are still far from commercial maturity [53]. We note that these regions are characterized by moderate levels of RE consumption over the period of analysis. Therefore, investment in energy R&D can contribute to the success of the energy transition in these regions. In Franche-Comté, this causality is bidirectional, high RE consumption encourages the region to dedicate more funds to renewable energy R&D spending.

At the regional level, few causal relationships between the economic structure of the region, measured by per capita industrial production, and the share of RE in final energy consumption are significant at the 5% level. A unidirectional relationship appears between these two variables running from industrial production per capita to the share of RE in final energy consumption in Aquitaine, Basse-Normandie, Franche-Comté, and Picardie, while in Alsace, this causality is bidirectional.

We also note the existence of a bidirectional relationship between nuclear electricity production and the share of RE in final energy consumption in the Basse-Normandie. Indeed, the historic development of the nuclear sector in the region has come at the expense of its renewable counterpart; nuclear still occupies a leading position in the region's electricity mix. The rise of new renewable energy sources, particularly wind power, has not been accompanied by a decrease in nuclear production in the region. Over the period 1990-2015, the share of RE in final energy consumption in the Basse-Normandie region increased by 47%, while the growth rate of nuclear production per capita is around 9%.

The results of the link between RE consumption and the set of explanatory variables also show that there is a bidirectional causality between the share of RE in final energy consumption and greenhouse gas emissions in the OD. Greenhouse gas emissions can be an important driver of RE consumption which in turn can contribute to the reduction of these emissions. In 1990, the reference year for international policies on greenhouse gas emissions, the overseas departments emitted 12 million tonnes of carbon dioxide equivalent (CO2e), i.e., only 2.4% of total French emissions. In that year, they emitted 6.2 tonnes of CO2e per capita, compared with 9 tonnes of CO2e for the inhabitants of Metropolitan France. In 2014, while France's overall greenhouse gas emissions decreased (from 521 to 415 million tonnes), emissions from Overseas France increased to 23 million tonnes, i.e., 5.6% of total French emissions. This means that in 2014, Overseas France emitted more greenhouse gases per capita (8.5 tonnes of CO2e) than metropolitan France (6.1 tonnes of CO2e). Nevertheless, it is important to note that greenhouse gas emissions result not only from consumption behavior and lifestyles but also from land-use and energy production systems, which vary considerably within Overseas France. Indeed, the high per capita greenhouse gas emissions in the overseas departments are the result of a high dependence on fossil fuels such as coal and oil. All the Overseas Departments use more than 80% fossil fuels for primary energy: 82% in French Guiana (2012), 99% in Mayotte (2011) and 93% in Martinique and Guadeloupe in 2012. Despite good conditions for developing hydropower, solar, geothermal and wind energy, RE is only considered as a complement to fossil energy sources, except for French Guiana and Reunion, which use hydropower to generate electricity.

Finally, we note the existence of a unidirectional causality running from population density to the share of RE in final energy consumption in Aquitaine, Auvergne, Bourgogne, Bretagne, Centre, Languedoc-Roussillon, Pays de la Loire and Poitou-Charentes; and a bidirectional causality between the score of environmental parties and RE consumption in the regions of Corsica, Midi-Pyrénées and Picardie.

b) Panel Causality Tests

The confirmation of cointegration between the variables suggests that there should be unidirectional or bidirectional causality between the variables in the study. Since cross-sectional dependence exists in our panel data, we use the causality test of Dumitrescu and Hurlin (2012) [54] to explore the relationship paths between the variables. This test uses a vector autoregression structure to find unobserved heterogeneity in stationary data and a regression technique for each panel cross-section to identify causal relationships between the variables.

The results of this test presented in Table 11 confirm the existence of unidirectional causality running from the level of economic development (Log_GDP), the level of economic growth (GR_GDP), the research and development expenditure level (Log_RDE), industrial production (Log_IP), the population density (DENS) and the score of environmental parties (SEP) to RE consumption. On the other hand, no bidirectional relationship was detected between the explanatory variables and the endogenous variable.

Table 11 Panel causality tests.

Variables	Causal Direction			Z-bar	Z-bar tilde	Variables	Causal Direction			Z-bar	Z-bar tilde
Log_GDP and SREC.TFEC	Log_GDP	-)	SREC.TFEC	9.08 ***	7.36***	**Log-GHGE and SREC.TFEC**	Log-GHGE	-)	SREC.TFEC	1.0043	0.55
	SREC.TFEC	-)	Log_GDP	0.62	0.24		SREC.TFEC	-)	Log-EGHGE	0.57	0.76
GR_GDP and SREC.TFEC	GR_GDP	-)	SREC.TFEC	9.57***	7.77***	**UR and SREC.TFEC**	UR	-)	SREC.TFEC	0.14	0.16
	SREC.TFEC	-)	GR_GDP	1.44	0.92		SREC.TFEC	-)	UR	1.009	0.56
Log_RDE and SREC.TFEC	Log_RDE	-)	SREC.TFEC	9.28***	7.53***	**DENS and SREC.TFEC**	DENS	-)	SREC.TFEC	14.93***	12.28***
	SREC.TFEC	-)	Log_RDE	0.70	0.30		SREC.TFEC	-)	DENS	3.13	2.34
Log_IP and SREC.TFEC	Log_IP	-)	SREC.TFEC	4.75**	3.71**	**SEP and SREC.TFEC**	SEP	-)	SREC.TFEC	3.87***	2.97***
	SREC.TFEC	-)	Log_IP	0.57	0.77		SREC.TFEC	-)	SEP	0.53	0.17

5. Conclusion

This article seeks to identify the determinants of RE consumption in the French regions during the period 1990-2015. We have shown through the estimation of a VECM model, that in the short term, economic growth measured by the real GDP growth rate positively affects RE consumption, while nuclear and industrial production per capita have a negative impact. It seems that, in the short term, nuclear energy is a barrier to the promotion of RE.

In the long term, estimates from the FM-OLS and DOLS models indicate that the level of development of the economy, measured by the log of GDP per capita, has a positive impact on the share of RE in final energy consumption. The results also show that research and development expenditure favors the use of renewable energy, which is largely dependent on population density. Finally, we show that at the regional level, the weight of “green” parties positively influences the development of RE.

The process of transition to RE is thus a complex process linked to regional characteristics of different natures: economic (GDP per capita), institutional or political (environmental party score), demographic (population density) and technological (R&D expenditure per capita). Our results allow us to identify certain key drivers for the deployment of RE and to recommend the reinforcement of RE promotion measures with the support of the regions and big firms. Investment in the field of RE should be increased by providing them with more financial support. In this sense, the "green debt" at low interest rates can be a solution. In addition, research and development activities should be developed in line with RE promotion strategies. Indeed, learning and experience effects reduce costs and speed up the process of RE extension. It is also recommended that incentives should not only take the form of physical capital, but also human capital, since population density positively affects RE consumption, which requires qualified staff and public participation in the process of RE promotion.

We also found that RE consumption depends on the score of environmental parties in regional elections. This indicator reflects the political orientation of the region to environmental concerns and reflects the degree of citizen mobilization in the environmental sector. Indeed, citizen participation in negotiations and public debates on environmental issues is at the heart of the changes in public action. In this context, civil society actors play an essential role in increasing citizens' awareness of environmental concerns. In fact, energy consumption varies according to the social, demographic and economic characteristics of citizens (households and individuals). They are solely responsible for preserving the environment [55]. It is therefore necessary to involve them through solidarity finance in the energy transition effort by committing them financially to join the dynamics of domestic projects. The promotion of RE depends thus to a large extent on proactive policies and adequate institutional mechanisms that will be implemented by each region to finance the development of renewable energy projects of territorial benefit.

The study of the determinants of RE consumption at the regional level is constructive in the sense that it contributes to the existing literature on the determinants of RE consumption, which so far has focused on cross-country studies. This work is a first step to overcome the absence of studies at the regional level. Nevertheless, the construction of an explanatory econometric model of the evolution of consumption for each RE source could provide different answers in comparison with the aggregate analysis since the different RE sectors are strongly linked to local natural resources (sun, wood, wind, rivers...). Therefore, the introduction of climatic and geographical variables in these models could explain the contrasting levels of RE consumption across the regions.

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Appendix

Table A1 Bivariate Granger non-causality test

Regions	Log_GDP and SREC.TFEC		GR_GDP and SREC.TFEC		Log_RDE and SREC.TFEC		Log_IP and SREC.TFEC		NEP.cap and SREC.TFEC		Log-GHGE and SREC.TFEC		UR and SREC.TFEC		DENS and SREC.TFEC		SEP and SREC.TFEC	
	Log_GDP → SREC	SREC → Log_GDP	GR_GDP → SREC	SREC → GR_GDP	Log_RDE → SREC	SREC → Log_RDE	Log_IP → SREC	SREC → Log_IP	NEP.cap → SREC	SREC → NEP.cap	Log-GHGE → SREC	SREC → Log-GHGE	UR → SREC	SREC → UR	DENS → SREC	SREC → DENS	SEP → SREC	SREC → SEP
Alsace	0.17	0.30	1.09	0.33	1.09	3.66**	3.82**	5.33***	0.03	0.12	0.68	0.02	1.70	2.06	0.25	2.53	0.07	0.22
Aquitaine	0.06	0.63	1.03	0.56	0.32	3.28	2.78**	3.91	1.61	1.50	2.45	0.12	0.97	0.03	11.16***	0.62	7.35***	0.32
Auvergne	3.75**	0.13	2.25	0.11	0.13	4.14**	2.73*	0.75			0.04	2.42	0.18	0.004	7.98***	2.04	2.86*	2.78*
B-Normandie	7.68***	4.55**	0.03	4.53**	9.31***	0.20	5.31**	0.27	6.59***	7.22***	0.79	0.94	0.23	0.56	0.48	1.97	0.002	4.28**
Bourgogne	0.19	5.78***	0.48	4.9**	0.98	16.5**	1.21	0.44			0.89	1.06	0.11	0.35	5.34**	2.72*	0.04	1.25
Bretagne	6.61***	0.53	0.90	0.67	0.92	0.32	0.47	1.20			2.26	0.17	2.75*	1.66	16.04***	1.12	0.85	0.11
Centre	0.004	2.20	0.56	2.12	2.45	0.74	1.29	0.01	0.58	0.63	4.42**	3.03*	1.17	0.91	12.02***	0 .05	3.79**	1.29
C-Ardenne	5.36**	0.05	8.61***	0 .008	1.85	0.01	1.14	5.10**	0.25	0.08	2.0	5.8***	0.23	22.3***	0.11	0.03	0.87	0.07
Corse	0.53	0.10	2.46	0.04	1.25	1.3	2.16	2.01			0.55	0.15	0.28	0.48	0.52	0.03	13.12***	5.51***
OD	0.33	0.001	20.73***	0.0003	1.96	7.45***	0.04	4.96**			7.63***	3.48**	0.23	16.24***	0.0007	18.2***	3.32*	1.10
F-Comté	12.55***	0.91	6.12	0.54	9.39***	13.08***	5.08**	1.51			0.007	0.06	0.26	1.29	1.28	7.36***	0.19	5.09*
H-Normandie	0.23	6.37***	14.5***	6.80***	0.00337	2.69	0.21	10.1***	1.46	4.8**	0.011	0.21	1.86	11.1***	0.77	4.6**	9.62***	2.49
Ile-de-France	1.68***	1.07	16.37***	1.23	7.65	0.04	0.64	0.12			1.77	6.9***	0.63	8.04***	0.31	4.44***	4.42**	0.79
L-Roussillon	1.04	0.05	0.31	0 .06	1.40	1.41	0.05	0.42			0.003	13.7	0.15	2.47	11.74***	2.14	0.21	3.8**
Limousin	0.27	4.23**	0.16	4.35**	1.75	4.36**	3.16*	5.69***			0.11	0.07	11.02***	0.98	1.14	0.19	2.37	1.41
Lorraine	0.69	0.44	0.17	0.59	1.55	19.15***	0.09	0.42	0.90	0 .69	0.63	0.35	0.38	3.27*	0.22	0.04	0.19	0.21
M-Pyrénées	4.71**	0.12	0.03	0.10	6.78***	0.04	0.06	1.88	0.03	0.49	1.47	3.48**	0.26	4.79**	0.05	1.43	6.21***	5.39**
NPDC	0.29	6.27***	16.34***	5.62***	0.02	2.37	0.68	1.57	1.64	0.97	0.75	0.79	1.64	21.1***	0.001	62.06***	7.73***	0.05
PDLL	3.83**	1.59	0.72	1.51	0.18	1.44	0.004	1.51			0.14	0.0003	0.025	8.69***	10.19***	0.49	0.31	3.66*
Picardie	4.19**	1.40	2.20	1.51	2.51	3.24*	24.87***	0.21			0.42	9.68***	8.17***	0.13	0.84	9.73***	3.76**	4.79***
P-Charentes	23.4***	7.87***	0.59	8.65***	4.61**	0.52	5.36**	5.92***	13.06***	0.87	0.15	0.37	0.006	2.44	27.73***	0.55	9.49***	0.02
PACA	1.14	0.01	0.70	0.02	0.0009	9.55***	0.01	1.7e-05			0.08	3.18*	0.01	0.69	1.57	0.27	3.45*	9.66***
R-Alpes	2.26	0.41	0.13	0.28	0.84	6.59***	0.07	0.52	0.05	0.63	0.0005	4.81***	1.15	0.36	1.01	1.20	0.99	0.89

*. **. *** The rejection of the null hypothesis of non-causality at the 10 %, 5 % and 1 % levels respectively.