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Causality relationships between renewable energy, nuclear energy and economic growth in France

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Abstract This paper analyzes the dynamics and quantitative relationships between renewable energy production, nuclear energy production and economic growth on the basis of quarterly data from 2001Q1 to 2012Q3 in France. We employ unit root tests, the augmented Dickey–Fuller and the Philips–Perron, Granger causality test and variance decompositions to uncover the extent and the magnitude of the relationship among variables. The econometric evidence seems to suggest that there is a unidirectional relationship between the economic growth and the nuclear electricity production, since the growth hypothesis is valid. While there is a unidirectional causality at short-term running from the renewable energy production to the primary production of all energies at 10 % level.

Keywords Nuclear energy · Renewable energy · Economic growth · Granger causality · Variance decompositions

1 Introduction

The energy is considered as one of the driving strengths of the economic growth in all countries of the world (Pokharel 2006). Since the seminal study of Kraft and Kraft (1978), motivated by the oil price shock of 1973, the relationship between energy consumption and economic growth has been abundantly studied in the economic literature. The Granger causality test has been widely used to examine the sense of causality between energy consumption and economic growth. The type of relationship can be classified into four testable hypotheses. First, if a unidirectional relationship running from energy consumption to economic growth is found, then the economy is said to be an energy-dependent one and any energy policy encouraging conservation might adversely affect economic growth. This is known as the growth hypothesis. This view has been supported by studies such as Narayan and Smyth (2005), Al-Iriani (2006) and Mehrara (2007), among others, support this hypothesis. Second, if the inverse relationship is found, i.e., causality running from economic growth to energy consumption, then energy policy will not affect economic growth, but changes in GDP will directly result in changes in energy consumption. It is also called the conservation hypothesis, recent studies such as Stern (2000), Oh and Lee (2004), Yuan et al. (2008), Narayan and Smyth (2008) and Apergis and Payne (2009), among others. Third, a bidirectional or mutual relationship confirms what is known as the feedback hypothesis. In the fourth case, no evidence of any relationship between the two variables is found. This is known as the feedback hypothesis. These findings have been supported by Masih and Masih (1997), Paul and Bhattacharya (2004) and Lee et al. (2008), among others. In the fourth case, there exists no causal relationship between the two variables. This is often known as the neutrality hypothesis. This view has been supported by studies such as Cheng (1995), Fatai et al. (2002) and Jobert and Karanfil (2007), among others. During the last two decades, there is a large volume of published studies describing the causal relationship between energy consumption and economic growth (see inter alia, Altinay and

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Karagol (2005); Apergis and Payne (2010); Ozturk (2010); Pirlogea and Cicea (2012)).

The topic of causal relationship between electricity consumption and economic growth has been well studied in the literature. This topic is studied by many authors using various methodologies for different time periods and different countries. Causality directions between electricity use and growth have been categorized into four types. The first type: neutrality hypothesis which is supported by the absence of a causal relationship between electricity consumption and real GDP; the second type is conservation hypothesis: It is called unidirectional causality from real GDP to electricity consumption; the third type is growth hypothesis: It implies that causality running from electricity consumption to real GDP; and the fourth type is feedback hypothesis: It implies that there is two-way (bidirectional) causality between electricity consumption and real GDP. The different results of this topic show that (31.15 %) supported the neutrality hypothesis, (27.87 %) the conservation hypothesis, (22.95 %) the growth hypothesis and (18.03 %) the feedback hypothesis. In this survey, Murry and Nan (1996) used dataset from 1970 to 1990, in which they find that there is no causal relationship (in either direction) between electricity consumption and real GDP in France. In the same way, Narayan and Smyth (2008) used data covering 1960–2002 and found no causality for the case of USA, UK and France. These mentioned studies not focused on some specifics energetic sources like renewable and nuclear energy. Recently, the relationship between nuclear and renewable energy use and economic growth has attracted significant research interest. Sari et al. (2008) investigated the causality linkages between renewable energy consumption and industrial output in the USA over the period of 1969–2009, and they supported the conservation hypothesis. Apergis and Payne (2010) found evidence of bidirectional short- and long-run causality between renewable energy consumption and economic growth for Eurasia and Central America countries. Wolde-Rufael and Menyah (2010) have analyzed the direction of causality between nuclear energy consumption and economic growth over the period 1971–2005 in nine industrialized countries; they found a bidirectional causality relationship for France, Spain, the UK and the USA.

For our study, the capacity of nuclear energy production exceeds domestic demand (measured by consumption). Since France considered exporting country of nuclear energy, it is the world's largest net exporter of electricity due to it's very low cost of generation and gains over EUR 3 billion per year from this, according to WNA. However, few efforts were made to test the sense of causality between energy production and economic growth. This study attempts to fill this gap by examining the relationship between energy production and economic growth, which aims at answering the following pertinent research question: Nuclear power could be replaced by renewable energy?

We will study this problem by analyzing a quarterly dataset for France from 2001 to 2012. This study is based on the traditional VAR model of Sims and Granger causality test assuming that data series are stationary. The rest of the paper is organized as follows. Section 2 presents economic role of nuclear and renewable energy. Section 3 presents an overview of the energy sector in France. Section 4 outlines the model and econometric methodology employed. Section 5 provides the empirical results and their discussion. Section 6 concludes the paper and offers some remarks on the results and some policy implications.

2 Economic role of nuclear and renewable energy

The environmental challenge in France, including numerous other imported energy-dependent countries, is how to improve the energy supply industry to produce safer and inexpensive energy, and simultaneously, how to reduce emissions of greenhouse gas (GHG) emissions. Any attempt to deal with global warming requires finding alternative energy sources to fossil fuels. Both nuclear and renewable (wind, solar hydro, biomass and geothermal) energy sources are supposed to provide some solutions to the problems of energy security and climate change. As with many other countries, within the framework of its strategy to reinforce energy security and deal with global warming, France is investing in nuclear and renewable energy not only to reduce dependence on oil imports, but also to increase the supply of secure energy, in order to minimize price volatility associated with oil imports and reduce greenhouse gas emissions (Vaillancourt et al. 2008; Adamantiades and Kessides 2009; Menyah and Wolde-Rufael 2010). According to (Stern 2011), energy plays a vital role in economic growth as a production factor, and the relationship between them is currently well established in the literature. Existing empirical studies on the nexus between nuclear energy and economic growth, Apergis and Payne (2010) find evidence of bidirectional causality between nuclear energy consumption and economic growth in the short-run, with unidirectional causality running from nuclear energy consumption to economic growth in the long run. Wolde-Rufael and Menyah (2010) offer evidence of unidirectional causality running from nuclear energy consumption to economic growth in Japan, while it runs from economic growth to nuclear energy consumption in Canada. Concerning the nexus between renewable energy and economic growth, Sadorsky (2009) presented evidence of bidirectional causality between non-hydroelectric renewable energy consumption and economic growth in emerging economies.

Bowden and Payne (2010) compared the causal relationship between renewable and non-renewable energy consumption and real GDP for the USA using annual data from 1949 to 2006. The author used Toda–Yamamoto causality tests in a multivariate framework and found no Granger causality between renewable and non-renewable energy consumption and real GDP. Our study aims to treat the relationship between nuclear energy and GDP one hand and renewable energy and GDP other, and integrate the primary production of all energies, where the goal is to find the possibility of indirect causality relationship.

3 Nuclear and renewable energy in France

At the beginning of the 20th century, energy production in France and Europe depended half on hydraulic channels and half on mineral fuels, mainly coal, Fiore (2006). After the Second World War, French government had to cope with considerable increase in power consumption induced by demographic growth, urbanization, industrialization and increased standard of living and industrialization which are referred to Trente Glorieuse. Until 1970, production growth has been provided by the completion of hydraulic equipment sites and especially the construction of power plants using coal and oil. Therefore, the shortage of mineral fuels in French government sparked the interest of the government for a new type of energy such as nuclear energy.

Following the oil shock in 1973, France decided to invest in a large-scale nuclear power to ensure energy independence. The French government managed by Pierre Messmer, decided in March 1974 to revive nuclear program. Currently, the French nuclear park comprises 58 nuclear reactors distributed on 19 standardized power plants; this program ranks the France as the second nuclear power in the world after the USA (sfen). The French nuclear sector is very controversial and occupies a large place in the current debate on future's energies and their environmental and sanitary impacts. Indeed, on the one hand, nuclear energy has real advantages. France generates 78 % of its electricity from nuclear energy with an installed capacity of 63,200 (MW) in 2011 and achieved an energy independence around 50 % (Cea). According to the report of Cea, nuclear energy avoids 700 million tons of carbon dioxide emissions (CO_2) per year. France emits on an average of 1.8 times less CO_2 than the Germany and of 2.9 less than the USA. Nuclear energy currently is by far the largest source of electricity production in France (78 %), and combined with hydropower (12 %), thus supplies 90 % of electricity, without greenhouse gas emissions. France is one of cleanest countries of the world in terms of CO_2 emission, with respect to its huge economic size. Nuclear industry also provides many jobs. In Europe, this industry supplies, directly or indirectly, and provides 400,000 jobs De Montesquiou (2000). The electricity production in France is currently one of the most competitive in Europe. Basic operating nuclear power, with a producing cost of 28.4 Euros per megawatt hour all taxes included (MWh ATI), is more competitive than natural gas (35 Euros/MWh ATI) and coal (32–33.7 Euros/MWh ATI) (DGEMP). These results include both present and future costs of the nuclear industry, that is, research and development, spent fuel reprocessing, the decommissioning and waste management.

On the other hand, nuclear energy is a very risky activity. Because it could generate many accidental risks during installations (explosion, radioactive leak…). Among the significant nuclear accidents in the world, the Chernobyl accident in 1986 which is the result of a flawed reactor design that was operated with inadequately trained personnel. The most contaminated regions were in southern Belarus, northern Ukraine and the Bryansk and Kaluga regions of Russia. The thyroid cancer, malformations in newborns and environmental problems (dead trees, contaminated grass, etc.) are the consequences for man and the environment in connection with the explosion. The contaminated water and its consumption were others. In France, thyroid cancer is characterized by low occurrence and good prognosis. However, the incidence of thyroid cancer has been increasing for more than 20 years, and in 1986, the Chernobyl cloud of radioactive dust crossed the French territory Bard et al. (1997). This augmentation is often perceived as one of the possible consequences of this accident although the Japanese nuclear accident as serious as Chernobyl. Explosions of devastating tsunami in 2011 have led to significant releases of radionuclides into the atmosphere. The various observations showed that the French regions were affected similarly, with spatial and temporal fluctuations due to the movement of air masses. These levels are consistent with the estimates from modeling conducted by the Institute for Radiological Protection and Nuclear Safety in collaboration with Météo-France. These concentrations were at levels of 500–1,000 times lower than those measured in early May 1986 France after the Chernobyl accident. Today, we present the solutions that we seek to harness the forces of nature, line wind, hydro and solar. If there are other solutions, which can only represent solutions or requires extra resources we are not equipped. With respect to the solar energy, it pulls at same time the direct rays of the sun but also diffuses radiation through the atmosphere. Energy from the sun can illuminate the Earth and heat. However, to use solar energy for other purposes, it is necessary to transform it. Solar energy is the most abundant of all renewable resources in Metropolitan France, with average 674 PWh of solar energy received annually (horizontal plane) (Suri and Dunlop 2005). The French solar photovoltaic energy accounted for 2.3 terawatt hour (TWh) in 2011 or 2,300 gigawatt hour (GWh), equivalent to the electricity consumption of more than one million people from France. PV capacity was 268 MW at the end of 2009 and 1,473 MW at half of 2011.

Thus, on average, 0.05 kW of photovoltaic energy is produced every second in France. The photovoltaic park has more than tripled between 2008 and 2009, with 185 MW linked during year 2009 while the fossil fuel power plant production is in decline, reaching 53.2 TWh in 2008, Suri and Huld (2005). Solar energy has many advantages because it is clean and inexhaustible. Other sources of renewable energy such as wind energy can be used for the conservation of mechanical energy, the transformation driving force (pumping liquids, fluid compression, etc.) and power generation. France has three geographical areas with high potential of wind energy: North Sea English Channel, the Atlantic Seafront (northern France) and the Mediterranean coast (southern France), Troen and Petersen (1989). According to planetoscope, the wind generation was 11.0 million MWh (11.9 TWh) and 2.5 % of electricity consumption in France 2011. In November 2011, the total installed wind power capacity in service is 6,397 MW. According to the survey conducted by the Environment Agency and Energy Management in July 2011, the perception of wind energy is positive and continues to improve. The wind is among the favorite of French renewable energy and plays a central role in the energy transition. The total theoretical potential for hydropower in France was estimated at 266 TWh/year, depending on geography and flow of rivers, Dambrine (2006). Planeteoscope showed that there are 2,250 hydroelectric plants in France, sizes and a wide variety of powers. The largest is located in Grand-Maison, in Isère, with an installed capacity of 1,800 MW, and more than 2,000 small works are scattered throughout the territory. This park with a capacity of 25,400 megawatts or 20 % of French electricity capacity today is for 13 % of national electricity production. The hydropower development will have a significant impact on the economy. According to a study by the Office of Information and Economic Forecast) for the SER in December 2012, nearly 10,000 direct, indirect and induced additional will be generated by the investment and operation of the sector in 2020.

Energy is a capital-intensive industry that is to say which are mobilized intensely productive capital. Today, nuclear movement trying to force an exit from nuclear power to move toward so-called renewable energy solutions. But is the substitution of nuclear power by renewable energy sources possible at present?

4 Data and methodology

The empirical evidence presented in this paper is carried out using the Granger causality test. This approach fits a standard vector autoregression model, Jbir and Zouari-Ghorbel (2009). Meanwhile, vector autoregressive (VAR) model, which is proposed by Christopher Sims, is extensively used as an analytical tool in econometrics to make comprehensive and dynamic analysis of several interrelated economic variables in non-stationary time series (Dees et al. 2007 and Gao 2009). Since the seminal work by Sims (1980), VAR model was applied to a vast range of empirical topics and various variables. It is as an approach that can be used to achieve comprehensive dynamic analysis of multiple interrelated economic variables and has the capacity to obtain predications of relative time series system and dynamic impact analysis to the variable system from the stochastic disturbance (Gao 2009). The dynamic interaction can be presented and estimated by the regression of lagged terms from one endogenous variable to all endogenous variables of the model in short and long term in detail, by which we can understand the impact from itself and the others. The basic expression is as follows:

$$\begin{aligned} y_t &= A_1 y_{t-1} + \ldots + A_p y_{t-p} + BX_t + U_t \\ t &= (1, 2, \ldots\ldots, T) \end{aligned} \tag{1}$$

where y_t is the endogenous variable vector and X_t is the exogenous variable vector; p acts as lagged intervals for endogenous variables; T indicates the number of samples; U_t can stand for white noise time series of vectors.

We used quarterly data on the gross domestic product, gross nuclear electricity production, primary production of all energies and gross production of hydropower and wind in France. Overall, this study has four variables. For this purpose, we employ Cobb–Douglas production function to investigate the relationship between renewable energy production, nuclear energy production, total energy production and economic growth. The extended VAR framework helps us to explore the relationship between the three energy variables and economic growth. The full sample comprises quarterly observations for the 2001:Q1–2012:Q3 period. The data are taken from the (Statistics Database-Eurostat).

Table 1 summarizes the descriptive statistics associated with the four variables. The empirical investigation is based on 47 quarterly observations. It is evident from the table that standard deviation (Std. Dev.) of GDP is highest and that of GPHW is the lowest. All variables have negative value of skewness indicating that the distribution is skewed to the left, with more observations on the right. The Jarque–Bera statistics shows that all variables used in the analysis have a normal distribution.

5 Empirical results

5.1 Results of the unit root tests

The Dickey and Fuller (1979, ADF) and Phillips and Perron (1988, PP) are standard tests that lead to non-rejection of a unit root could be considered suspect when the sample

Table 1 Descriptive statistics

	GDP	PPAE	GNEP	GPHW
Mean	437,994.8	30,347.07	27,950.71	1,319.706
Median	444,528.0	29,853.16	27,430.94	1,352.110
Maximum	499,746.0	34,766.92	32,990.68	2,049.270
Minimum	366,068.0	25,020.36	11,198.02	52.13000
Std	44,083.76	2,862.197	3,697.572	465.5592
Skewness	−0.262003	−0.031247	−1.870700	−1.313963
Kurtosis	1.656300	1.698020	9.913856	4.940213
Jarque–Bera	4.073554	3.327323	121.0240	20.89624
Probability	0.130448	0.189444	0.000000	0.000029
Sum	20585757	1426312.	1313683.	62,026.17
Sum	8.94E + 10	3.77E + 08	6.29E + 08	9970286.
Observations	47	47	47	47

GDP gross domestic product, *GNEP* gross nuclear electricity production (ktoe), *PPAE* primary production of all energies (ktoe), *GPHW* gross production of hydropower and wind (ktoe)

includes economic events may cause changes in the regime. We conduct tow different unit root tests, namely augmented Dickey–Fuller (ADF) and Phillips-Perron (PP), and the ADF and PP tests suggest stationarity at least at the 5 % significance level. According to these results, it was assumed that all the time series are stationary after one differentiation. Table 2 shows that for all variables, we cannot reject the unit root test. Thus, they are integrated with order one (I (1)) and stationary in first difference. Following these results, we can use the VAR model, which deals the short-term relationship, Jbir and Zouari-Ghorbel (2009).

The results of these tests are shown in Table 2; we also find that gross domestic product is strongly exogenous with only small influences from gross nuclear electricity product, gross production of hydropower and wind and primary production of all energies.

5.2 Granger causality tests

Granger causality test has been widely used by Granger (1969) in the literature. The Granger causality tests have been widely used to study the relationship among two or more variables. The basic idea behind Granger causality tests is as follows: If X and Y are two variables, X is said to Granger causes Y if the prediction of the current value of Y is improved by using past values of X.

Since the development of this statistical hypothesis test, some of studies on the properties of the various test methods have been published, Jbir and Zouari-Ghorbel (2009), Belloumi (2009), Mantalos and Shukur (2010), Mazbahul and Nazrul (2011) and Sung and Song (2013).

The equation of conventional Granger test could be written as

$$Y_t = \gamma + \sum_{i=1}^{m} \alpha_i Y_{t-i} + \sum_{j=1}^{n} \beta_j X_{t-j} + \varepsilon_t \tag{2}$$

To detect the causal relationship between PPAE and GDP is defined as follows:

$$GDP_t = \gamma + \sum_{i=1}^{m} \alpha_i PPAE_{t-i} + \sum_{j=1}^{n} \beta_j GDP_{t-j} + \varepsilon_t \tag{3}$$

$$PPAT_t = \gamma + \sum_{i=1}^{m} \alpha_i PPAE_{t-i} + \sum_{j=1}^{n} \beta_j GDP_{t-j} + \varepsilon_t \tag{4}$$

From the aforementioned Granger causality representations, it seems that:

a. There is a unidirectional causality from PPAE to GDP if:

$$\sum_{i=1}^{m} \alpha_i \neq 0 \quad \text{and} \quad \sum_{i=1}^{n} \beta_j = 0 \tag{5}$$

b. Quite the reverse, a unidirectional causality from GDP to PPAE will be found if:

$$\sum_{i=1}^{m} \alpha_i = 0 \quad \text{and} \quad \sum_{i=1}^{n} \beta_j \neq 0 \tag{6}$$

c. There will be bidirectional causality or feedback between GDP and PPAE if both the conditions:

$$\sum_{i=1}^{m} \alpha_i \neq 0 \quad \text{and} \quad \sum_{i=1}^{n} \beta_j \neq 0 \tag{7}$$

d. GDP and PPAE will be determined independently and not statistically significant if:

$$\sum_{i=1}^{n} \alpha_i = 0 \quad \text{and} \quad \sum_{i=1}^{n} \beta_j = 0 \tag{8}$$

It is the absence of a causal relationship between the two variables.

Table 3 reveals results of Granger causality within VAR framework. The results presented provide convincing evidence of a unidirectional causality running from GNEP to economic growth proxied by GDP at 5 % level. We therefore reject the null hypothesis that GNEP does not Granger cause real GDP and conclude that GNEP actually affects real GDP, which supported the growth hypothesis. On the contrary, there is a unidirectional relationship from GDP to GPHW at 5 % level, this implies

Table 2 Unit root test (ADF and PP)

Variables	Level			1st Difference		
	(1)	(2)	(3)	(1)	(2)	(3)
ADF test						
GDP	2.190164	−1.522671	−2.339726	−2.936618**	−2.886227**	−3.207061**
PPAE	−0.312291	−2.667924*	−3.627874**	−3.045604**	−2.974216**	−3.114562**
GNEP	−0.233734	−6.322314***	−6.337985***	−7.911221***	−7.805892***	−7.718077***
GPHW	0.381642	−6.600083**	−4.723218***	−6.009953***	−6.223738***	−6.839018***
Phillips–Perron test						
GDP	4.656290	−1.051618	−1.616931	−4.936430***	−7.176048***	−7.492536***
PPAE	−0.646464	−5.612542***	−5.762168***	−12.81109***	−12.55709***	−14.09606***
GNEP	−0.581594	−6.300295***	−6.348651***	−19.97730***	−19.70849***	−19.85141***
GPHW	−0.576160	−3.803154**	−4.468159***	−8.133231***	−8.772345***	−10.27823***

Critical levels in the model: (1) −2.60 (1 %), −1.95 (5 %) and −1.61 (10 %).Critical levels in: (2) −3.51, −2.89 and −2.58. Critical levels in: (3) −4.04, −3.40 and −3.15

GDP gross domestic product, *GNEP* gross nuclear electricity production (ktoe), *PPAE* primary production of all energies (ktoe), *GPHW* gross production of hydropower and wind (ktoe), (1) Without intercept, (2) with an intercept and (3) with an intercept and trend. ***, ** and * mean a *p* value < 1, 5 and 10 %

that due to expansion of the real GDP, France is consuming more renewable electricity, and there is a unidirectional relationship from GNEP to GPHW at same level, which implies that there is two-way (bidirectional) causality between GNEP and PPAE at 5 % level, is confirmed for France, while there is a unidirectional causality from GPHW to PPAE at 10 % level. Results show the big interdependence between nuclear energy and the French energetic system. On the other hand, nuclear energy production has an important role in increasing GDP growth. Therefore, based on the obtained results, it is important for France to increase their investment in nuclear energy projects to boost their share of total energy use since it increases GDP growth. The unidirectional causality from GDP to renewable energy shows that French economic development can encourage investment in renewable energy sector. Consequently, renewable energy consumption can be an important solution to reduce the environmental damage.

5.3 Variance decomposition

Variance decomposition indicates the proportion of the movements in the dependent variables which are due to their "own" impacts, against shocks to the other variables. This method does not allow assessing the percentage of the variance of the forecast error explained by each variable in absolute terms, but only in relative terms. These statistics measure the quantitative effect that the shocks have on the variables (Enders 2004). Diebold and Yilmaz (2009) introduce a volatility spillover measure based on forecast error variance decompositions from vector autoregressions (VARs).

Considering N covariance stationary variables VAR (p),

$$y_i = A \sum_{i=1}^{p} \phi_i y_{t-1} + \varepsilon_i \tag{9}$$

In which y_i is a (4×1) vector of jointly determined endogenous variables, $\varepsilon \rightarrow (0, \theta)$ is the vector of IID

Table 3 VAR Granger causality/block exogeneity Wald tests

Dependent variables	Excluded variables			Block exogeneity	
	GDP	PPAE	GNEP	GPHW	All variables together
GDP		1.521276 [0.2174]	4.662789** [0.0308]	2.354202 [0.1249]	14.51706** [0.0023]
PPAE	0.350494 [0.1709]		8.736228** [0.0031]	3.427097* [0.0641]	5.096793* [0.0648]
GNEP	0.165976 [0.6837]	4.210914** [0.0402]		0.441003 [0.5066]]	1.967743 [0.5791]
GPHW	6.859410** [0.0088]	0.865576 [0.3522]	20.99318** [0.0000]		28.82183** [0.0000]

Significance of each other lagged endogenous variables in that equation. The statistics in the last column is the Chi-square statistics for joint significance of all other lagged endogenous variables in the equation

**,* significant at 5 and 10 %

Table 4 Variance decomposition: Cholesky ordering: GDP GNEP GPHW PPAE and standard errors: Monte Carlo (100 repetitions)

Variance decomposition of GDP

Period	SE	GDP	GNEP	GPHW	PPAE
1	3,698.614	100.0000 (0.00000)	0.000000 (0.00000)	0.000000 (0.00000)	0.000000 (0.00000)
2	5,783.844	88.73411 (5.88328)	9.969252 (6.04505)	0.414490 (1.26836)	0.882146 (1.68950)
3	7,060.723	84.61046 (8.15578)	12.72119 (8.14423)	2.018592 (3.49106)	0.649752 (1.71093)
4	7,972.457	82.73294 (9.42486)	13.25263 (8.94442)	3.468170 (5.16268)	0.546256 (1.51018)
5	8,742.857	81.88545 (10.1450)	13.30169 (9.31440)	4.295223 (6.08719)	0.517635 (1.43923)
6	9,448.980	81.45239 (10.5376)	13.33979 (9.60353)	4.729057 (6.56940)	0.478757 (1.42724)
7	10,106.17	81.14161 (10.7772)	13.41612 (9.85551)	5.003946 (6.87495)	0.438327 (1.43024)
8	10,715.84	80.88034 (10.9887)	13.49448 (10.0763)	5.219736 (7.12179)	0.405448 (1.44395)

Variance of GNEP			Variance decomposition of GNEP		
Period	SE	GDP	GNEP	GPHW	PPAE
1	3,819.871	0.277073 (2.82013)	99.72293 (2.82013)	0.000000 (0.00000)	0.000000 (0.00000)
2	3,848.653	0.803490 (3.54713)	98.23948 (5.44967)	0.671778 (1.84646)	0.285251 (2.43287)
3	3,864.140	1.085835 (3.78893)	97.66035 (6.56114)	0.729795 (2.20080)	0.524016 (2.63885)
4	3,866.001	1.112043 (3.85388)	97.61420 (6.83911)	0.737284 (2.19453)	0.536471 (2.78680)
5	3,866.398	1.112772 (3.85968)	97.59517 (6.96919)	0.752047 (2.27977)	0.540008 (2.82701)
6	3,866.581	1.115268 (3.86711)	97.58594 (7.04538)	0.755508 (2.31952)	0.543278 (2.84000)
7	3,866.763	1.123302 (3.87602)	97.57725 (7.07398)	0.755940 (2.33283)	0.543513 (2.84401)
8	3,867.011	1.133890 (3.89452)	97.56646 (7.09544)	0.756201 (2.33901)	0.543446 (2.84637)

Variance decomposition of GPHW

Period	SE	GDP	GNEP	GPHW	PPAE
1	270.2938	14.39239 (9.58782)	8.027061 (6.95100)	77.58055 (10.4160)	0.000000 (0.00000)
2	383.9798	24.28591 (9.49099)	11.93594 (9.11344)	49.02716 (9.15831)	14.75099 (5.60834)
3	401.8645	24.61127 (9.50768)	14.61251 (10.4889)	44.77274 (9.37726)	16.00348 (6.47426)
4	403.3507	24.44186 (9.54408)	14.69315 (10.6096)	44.97090 (9.36702)	15.89409 (6.42610)
5	404.1301	24.34923 (9.56845)	14.65046 (10.6493)	44.99674 (9.38835)	16.00357 (6.53801)
6	404.3299	24.37167 (9.56536)	14.63796 (10.6819)	44.96785 (9.41296)	16.02253 (6.59517)
7	404.6315	24.47010 (9.55587)	14.62915 (10.6819)	44.90207 (9.40840)	15.99869 (6.57919)
8	404.9914	24.57000 (9.55650)	14.63249 (10.6772)	44.82648 (9.41224)	15.97104 (6.55874)

Variance of PPAE

Period	SE	GDP	GNEP	GPHW	PPAE
1	2,842.458	24.94972 (9.88875)	31.37766 (9.92299)	4.342797 (3.42876)	39.32981 (8.07424)
2	2,919.618	23.67311 (9.56902)	32.15550 (9.96520)	6.615634 (4.56524)	37.55575 (7.40279)
3	2,984.979	24.04217 (9.44927)	31.11959 (10.0139)	7.714503 (5.29677)	37.12373 (7.16172)
4	3,002.233	24.07179 (9.41538)	31.17042 (10.0323)	7.664712 (5.18345)	37.09308 (7.15009)
5	3,003.265	24.05598 (9.41718)	31.18169 (10.0541)	7.692245 (5.28696)	37.07008 (7.16159)
6	3,003.903	24.05235 (9.40940)	31.17054 (10.0554)	7.708410 (5.31691)	37.06870 (7.15318)
7	3,004.033	24.05047 (9.40477)	31.17031 (10.0548)	7.708914 (5.32546)	37.07031 (7.15079)
8	3,004.061	24.05180 (9.40567)	31.16972 (10.0583)	7.708809 (5.33248)	37.06967 (7.15187)

disturbances, ϕ_1 through ϕ_p are (4×1) coefficient matrices; A is a vector of constants. In addition, Diebold and Yilmaz (2012) used the generalized VAR framework proposed by Pesaran and Shin (1998); he constructed a variance decomposition invariant to commanding. Let us denote the generalized forecast error variance decompositions by:

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ij}^{-1}\sum_{h=0}^{H-1}\left(e_i' A_h \sum e_j\right)^2}{\sum_{h=0}^{H-1}\left(e_i' A_h \sum A_h' e_i\right)} \quad (10)$$

where $\sum$ is the variance matrix for the error vector ε, σ_{ij} is the standard deviation of the error term for the *jth* equation and e_i is the selection vector, with one as the *ith* element and zeros otherwise. Table 4 shows the results of the forecast error variance decomposition of the variables. The decomposition is taken temporally with respect to the source of disturbance. The methodology uses Monte Carlo methods to estimate the variance decomposition. Median forecast error variance decompositions are computed up to a horizon of 2 years (eight quarters). The impact of GNEP on GDP is 13.49 percent by the first two quarters, which is higher than the impact of GPHW which is almost (5.22 %) which shows that the GDP is more dependent on nuclear compared to renewable energy. Results of variance decomposition approach find bidirectional causality between nuclear electricity production and economic growth in France in short-run, which supported the feedback hypothesis. The results are consistent with the findings by Wolde-Rufael and Menyah (2010) who found bidirectional causality between nuclear energy consumption and economic growth.

Our results show that most of the variation in the forecast error for primary production of all energies comes from shocks to gross nuclear electricity production which exceeds 97 % after eight quarters. That is, approximately 0.76 % of the variability in primary production of all energies can be explained by shocks of GPHW to over eight quarters, which still gives a great relationship between PPAE and GNEP, while GPHW constitutes as marginal over to PPAE. Approximately 24.57 % of the variation in GPHW results from GDP shocks over 8-quarter period, which checks the unidirectional relationship between GDP and GPHW. This result is consistent with some empirical study as Payne (2011) which found a positive unidirectional causality from economic growth to renewable energy implying the presence of the conservation hypothesis. On the other hand, other studies have found no causality and/or bidirectional causality between renewable energy use and real GDP (e.g., Menegak (2011); Salim and Rafiq (2012); Pao and Fu (2013)). Nuclear energy is arguably one of the best sources for French electricity generation that can meet the future needs and requirements. Even so, advances and improvements must be made for renewable energy to be competitive in the future. To continue the development of new green energy sources and renewable energy markets, the French government should introduce more preferential policies, such as investment subsidies or tax incentives, sales tax and green certificate trading, to promote the development of a clean energy economy.

6 Conclusion

The environmental challenge facing many countries including France is how to balance the energy needs, the energy supply industry to produce most secure and cheap energy, simultaneously reduce greenhouse gas emissions and to protect the environment. The study has investigated the causality relationship between gross nuclear electricity product (GNEP), gross production of hydropower and wind GPHW, primary production of all energies PPAE and economic growth in France during the period of 2001Q1–2012Q3. The current study further establishes the Granger causality running from real GDP and GNEP to GPHW without any feedback effect implying that the economic growth and the nuclear electricity are responsible for the variation of renewable energy production in France. Our study finds also bidirectional short-run causality between the GNEP and PPAE at 5 % level, while there is unidirectional causality from short-term running the GPHW to the PPAE at 10 %. Our results show that the nuclear energy is important to serve needs of French people. It is very difficult to replace the nuclear energy with another energy resource such as the renewable energy. Nuclear energy production in France is a technological revolution which aims at improving economic development. Compared to alternative sources, this energy factor is exceptional. Macro-economically, nuclear energy must not be drawn aside and, undoubtedly, should be coupled with other sources of energy and complementary measures of development, due to the strong correlation between GDP and nuclear energy production, as shown by results. On the other hand, micro-economically, allow French consumers to benefit from the low-cost nuclear power, which they financed with their prior investments in retail rates. Therefore, environmental policies to conserve nuclear energy consumption may weaken the economic growth and development in France.

The feedback hypothesis (according to variance decomposition approach) was confirmed showing possible complementarities between nuclear energy use and economic growth in short term. This result supported by Wolde-Rufael and Menyah (2010) which found a bidirectional causality running between economic growth and nuclear energy consumption in France, Spain, the UK and the USA. Sari et al. (2008) investigated the relationship between renewable energy consumption and industrial output using ARDL approach in the USA over the period of 1969–2009, and they supported the conservation hypothesis. Sadorsky (2009) studied the relationship between renewable energy and economic growth; he confirmed that economic growth has a significant effect on increasing renewable energy consumption. However, Marques and Fuinhas (2012) suggested negative impact of using renewable energy on economic growth and that in turn, economic growth does not contribute to increased renewable energy consumption that supported neutrality hypothesis.

This debate requires deepening to find alternative resources with the objective to achieve a balance between people's satisfactions with the energy challenges and to keep the world green and a sustainable environment. In many countries, precisely in France, there is a considerable interest in the development of nuclear energy as a means to ensure energy security and stabilization and/or reduction in greenhouse gas (GHG) emissions, but also economic necessity should not outweigh the risks. Nuclear safety is a worldwide concern that requires a global solution. The appropriate balance must be struck between the pursuit of economic growth, nuclear security, clean energy and drive to make the country a relatively independent power. The shift away from nuclear energy should accelerate opportunities for developing alternative clean energy sources in France in the near future. However, further analysis is required to assess in greater depth the influence of limiting factors such as the variability of certain resources, the distribution and transmission constraints and the potential usage conflicts. Other incentive policies to promote renewable energy include investment subsidies or rebates, tax incentives or credits, sales tax exemptions and green certificate trading. Renewable energy are now the most dynamic sector of the energy mix and offer hold great potential to deal with issues of energy security and sustainability. Finally, French-speaking African countries show a growing interest for the development of renewable energy (such as in Morocco or Tunisia). Opportunities for investment in renewable energy in Africa must diversify in the near future.

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