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Electricity generation mix and economic growth: What role is being played by nuclear sources and carbon dioxide emissions in France?

André Francisco Roque Nunes

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Orientador: Prof. Doutor António Manuel Cardoso Marques

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Acknowledgments

I would like to dedicate this page to the persons that in different forms helped to overcome this important stage of my life.

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Resumo

A presente dissertação visa analisar a interação simultânea entre as várias fontes de produção de eletricidade e o crescimento económico. Esta pesquisa foca-se em França, utilizando dados mensais a partir de Janeiro de 2010 até Novembro de 2014. Para analisar as diferentes dinâmicas de interação utilizou-se o modelo autorregressivo (ARDL). Esta metodologia permite fazer uma distinção entre efeitos de curto e de longo prazo. Os resultados demostram que a energia nuclear tem sido uma grande impulsionadora do crescimento da economia Francesa, e na diminuição das emissões de CO2. Sendo que, as energias renováveis revelam ter um efeito negativo no crescimento económico. De fato, este efeito pode ser causado pela falta de investimentos na implementação de energias renováveis, devido à posição dominante da energia nuclear, no sistema electroprodutor Francês. A robustez dos resultados foi verificada com dados anuais, de 1970 até 2012, através dos quais os resultados obtidos são comparáveis com os dos dados mensais, verificando o efeito de substituição entres as fontes de geração de eletricidade.

Palavras-Chave

Nexus eletricidade-crescimento; ARDL bounds test, emissões CO2, mix geração eletricidade, nuclear,França

Resumo Alargado

A procura de eletricidade encontra-se em crescimento devido à expansão das populações, principalmente em economias emergentes. Na verdade, a geração de eletricidade tem implicado um aumento das emissões de gases efeito de estufa. Para satisfazer este aumento de procura de eletricidade de forma sustentável, os sistemas electroprodutores têm explorado as fontes de energia renováveis de forma a substituir as fontes de energia fósseis. Com o aumento da implementação de energias renováveis, os sistemas electroprodutores deparam-se com novos desafios, nomeadamente: (i) a interação das diversas fontes de produção de eletricidade na satisfação da procura, (ii) a relação entre as diversas fontes e o crescimento económico, e (iii) o impacto das fontes de eletricidade nas emissões de CO2.

A análise da relação entre consumo de energia e crescimento económico é um tema bastante debatido na literatura, sendo denominado de *nexus* consumo de eletricidade e crescimento económico. Na literatura, foram definidas quatro hipóteses para explicar as relações de causalidade entre as variáveis: (i) hipótese de crescimento; (ii) hipótese da conservação; (iii) hipótese de feedback e (vi) hipótese da neutralidade. A hipótese de crescimento sugere que o consumo de eletricidade causa o crescimento económico, ou seja uma relação unidirecional do consumo de eletricidade para o crescimento económico. De acordo com a hipótese de conservação, o crescimento económico gera consumo de eletricidade, indicando a presença de uma relação unidirecional entre crescimento e consumo de eletricidade. A hipótese feedback sugere que o consumo de eletricidade e o crescimento económico se causam mutuamente, indicando assim a presença de uma relação bidirecional entre crescimento económico e consumo de eletricidade. A hipótese da neutralidade sugere que não existe qualquer relação causal entre o crescimento económico e o consumo de eletricidade.

A análise inicial deste *nexus* centrava-se no consumo primário de energia, proveniente de todas as fontes disponíveis (eletricidade, fontes fosseis e derivados das mesmas). Contudo, *nexus* mais especializados surgem, eletricidade-crescimento económico, sendo diferenciado em fontes renováveis e não renováveis (*nexus* energia renovável-crescimento económico e *nexus* energia não renovável-crescimento económico). Estas novas abordagens são explicadas, utilizando as mesmas quatro hipóteses que o *nexus* tradicional. Alguns investigadores como Sebri (2015) e Wang et al.(2015) afastam-se um pouco do *nexus* tradicional, incorporando outras variáveis, nomeadamente variáveis ambientais.

Este trabalho tem como objetivo contribuir para a literatura atual, analisando a relação entre diferentes fontes de produção de eletricidade, emissões de CO2 e atividade económica (como proxy do crescimento económico) em França. As diferentes fontes de produção de eletricidade são estudadas de forma desagregada (petróleo, carvão, gás, nuclear, hidroelétrica, eólica, fotovoltaica e outras renováveis) e agregada (fóssil, nuclear, hidroelétrica e renovável). França possui um mix de produção diversificado e a sua principal fonte de produção de eletricidade é a nuclear. Como membro da União europeia também possui várias metas ambientais, metas essas que têm como objetivo uma redução das emissões de CO2. Desta forma, a presente investigação pretende verificar de que forma o mix de produção de eletricidade interage entre si, e que efeito tem no crescimento económico e nas emissões de CO2.

Para a elaboração do estudo foram utilizados dados mensais de Janeiro de 2010 até Novembro de 2014. A produção de eletricidade foi analisada de forma agregada (fóssil, renovável, nuclear e hidroelétrica), e desagregada (carvão, gás, petróleo, nuclear, eólica, fotovoltaica, outras renováveis e hidroelétrica). A bombagem também foi incluída pois a mesma é crucial para garantir a estabilidade do sistema electroprodutor. Como *proxy* de crescimento foi utilizado o índice de produção industrial (IPI), e como componente ambiental incorporou-se as emissões de CO2 provenientes da produção de eletricidade. Todas as variáveis foram convertidas em logaritmos naturais.

Para responder à questão central da investigação, foi utilizada a metodologia ARDL *bounds test* proposto por Pesaran et al., (2001). Este tipo de modelo suporta variáveis estacionárias em nível, e variáveis estacionárias nas primeiras diferenças, suporta também a inclusão de variáveis dummies. A metodologia ARDL também tem a capacidade de transmitir resultados viáveis mesmo com amostras pequenas, permite também a distinção entre efeitos de curto e de longo prazo. Foram estimados vários modelos para analisar os efeitos entre as fontes de produção de eletricidade e a atividade económica. Consequentemente, os modelos têm como variáveis dependentes: IPI, as fontes fósseis (*FOSSIL*), a nuclear (*NUC*), a hidroelétrica (*HYDRO*) e as fontes renováveis (*RES*). Devido ao problema de multicolinearidade, e para ultrapassar o mesmo foram criados modelos paralelos com a inclusão das emissões de CO2 e exclusão das fontes fósseis. Após as estimações, foi efetuado um controlo aos resíduos de forma a garantir as propriedades econométricas desejáveis para as estimações. Os testes de Normalidade (Jarque-Bera), autocorrelação (Breusch-Godfrey) e heterocedasticidade (ARCH) mostram que os resíduos têm uma distribuição normal, não possuem autocorrelação nem heterosticidade até ao terceiro desfasamento. Os testes de estabilidade CUSUM e CUSUM of squares e Ramsey RESET test, mostram a estabilidade dos modelos ao longo do período.

Os resultados demonstram que a presença da nuclear no sistema electroprodutor francês gera crescimento económico, contribuindo também para a diminuição das emissões de CO_2. No entanto, as fontes de energia renovável têm efeitos dissimilares na atividade económica. Por um lado, a energia solar fotovoltaica contribui para o crescimento económico, por outro lado, a presença da energia eólica nos sistemas electroprodutores tem um efeito negativo no crescimento económico. As emissões de CO_2 têm impulsionado a implementação das fontes de energia renováveis. É também comprovado o efeito de substituição entre as diversas fontes de produção de eletricidade. Como robustez a mesma metodologia foi aplicada aos dados anuais, iniciando em 1970 até 2012, os resultados obtidos através desses dados revelam consistência com os resultados obtidos através da frequência mensal.

Abstract

The gradual trend towards the electrification of the economies has raised new challenges. Focusing on France, this dissertation uses monthly data from January 2010 to November 2014, to study the challenge of the simultaneous integration of various sources of generation and their relationship with economic growth. For the analysis of the dynamics of interaction between electricity sources, the auto-regressive distributed lag (*ARDL*) bounds test approach was shown to be appropriate, as it allows short- and long-run effects to be distinguished. The results indicate that nuclear energy has been a huge driver of economic growth in France, meanwhile leads to an environment with lower *CO2* emissions. Renewables were shown to exert a negative effect on economic growth, which could be due to lack of investment in other sources of production due to the resilient position held by nuclear source. The substitution effect among sources is noticeable. The robustness of the results was checked with annual data, from 1970 until 2012, and the results are comparable with those from the monthly data.

Keywords

Electricity-growth nexus; ARDL bounds test, CO2 emissions, electricity mix, nuclear, France.

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Acronyms list

UBI – University of Beira interior.

CO_2 – Carbon dioxide emission.

TCO2 – Carbon dioxide emission total economy.

ECO2 – Carbon dioxide emission from electricity production.

NUC- Electricity produced from a nuclear source.

GDP – Gross domestic product.

IPI – Industrial production index

ARDL – Autoregressive lag model.

ECM – Error correction mechanism.

RES – Renewable energy sources.

PV – Photovoltaics.

HYDRO – Hydroelectric.

INSEE - Institut National de la Statistique et des Études Économiques.

RTE - Réseau de Transport d'Électricité.

ENTSO-E - European Network of Transmission System Operators.

JB – Jarque-Bera statistic.

LM - Breusch-Godfrey autocorrelation test.

ARCH - Autoregressive conditional heteroscedasticity teste.

RESET - Ramsey regression equation specification error test.

CUSUM - Cumulative sum control chart.

CUSUM of Squares - Cumulative sum of squares.

ADF - Augmented Dickey-Fuller test.

PP - Phillips and Perron test.

KPSS - Kwiatkowski Phillips Schmidt test.

IEA - International Energy Agency.

TSO - Transmission System Operator.

EKC - Environmental Kuznets Curve.

1. Introduction

The relationship between electricity consumption/production, economic growth, and environmental awareness has become a major concern for every country worldwide. To produce electricity some countries resort to the use of oil-related products, growing their energy dependence. The oil dependence and the volatility of the oil market forced countries to encounter an alternative and stable way to produce electricity to support their economic activities (Ben et al., 2015). Due to the growing electricity demand, countries started to raise their installed capacity, although this development started without environmental awareness. Such development leads to pressure from global institutions regarding environmental issues which forced governments to rethink their energy policies. In this context, countries are looking for new combinations of electricity sources to cope with this imperative of caring for the environment, while using endogenous electricity sources. In the face of this, policymakers need to know the consequences of the utilisation of each source on the economic growth, in order to accomplish the greater objective of guaranteeing economic growth in both an environmentally and economically sustainable way.

France is a major player in nuclear energy (Ben et al., 2015). However, this country is also committed to the challenging the European Union targets to incorporate renewable energy sources (*RES*) into the electricity generation mix. According to Hubert and Vidalenc (2012), France has a significant potential for *RES*, raising the question which renewable source best fits France. This high dependence on the high-scale efficient nuclear source, but non-flexible, together with the need to increase the penetration of the *RES*, without neglecting either the environment or economic growth, inspired the central research question of this dissertation: how are the electricity sources interacting within the France's electricity generation mix, and what are their relationships with both the carbon dioxide ($CO2$) emissions and the economic growth? In order to answer this, the auto-regressive distributed lag (*ARDL*) bounds test approach was used. Among the numerous advantages of this method, in particular, it allows conclusions to be made about causality relationships (Jouini, 2015), as well as about the effects observed both on the short- and on the long-run.

This study contributes to the most up-to-date literature, which is studying the electricity production – economic growth nexus. It innovates by analysing not only the relationships between electricity generation sources and economic growth but also, by considering the dynamics of adjustment and the interactions of these sources. As such, the distinct technological characteristics of each source are implicit in the analysis. Overall, the investigation confirms that each source can provoke different effects on the economic growth. This fact reinforces the validity of this option to slice the effects by source.

Each of the four traditional hypotheses of the energy-growth nexus was tested, not only for all the sources together but also for each specific source simultaneously. Finally, the Nexus is appraised, controlling for the potential environmental damage, which is represented by *CO2* emissions. On the whole, the results support: (i) the feedback hypothesis between nuclear source and economic growth; (ii) the role of *CO2* emissions as a driver of deployment of *RES*; (iii) the negative impact of some *RES* on economic growth, namely the wind power, on contrary to the solar photovoltaic; and (iv) the substitution effect between renewables and natural gas, on contrary of coal and oil that grow simultaneously with renewables. The main achievements of this study could be crucial to informing policymakers' decisions about how to design the electricity mix policies for the future, without compromising either economic growth or the environment.

The remainder of this study is organized as follows: the Section two reviews the literature; the section three discusses the French electricity system; the section four provides an overview of the data and methodology; Section five shows the results; Section six is dedicated to the robustness check of the results; finally, the sections seven and eight present the discussions and the conclusions, respectively.This dissertation has been published in the International Journal Energy Policy (dx.doi.org/10.1016/j.enpol.2016.01.027).

2. Literature Review

The literature centred on the energy consumption – economic growth nexus was experienced several headways, namely by making a path from general to the specific. By other words, the nexus is nowadays studied, not only looking for the relationships between the total primary energy consumption and the output but also for the specific relationships between the several energy sources and the economic growth, with a particular emphasis on the electricity. This fact has permitted enlarging the richness of the analysis. In the recent literature, the energy-growth nexus using the aggregate approach of total energy is used for example by Kyophilavong et al. (2015), and Tang et al. (2016). The narrowing of the nexus towards electricity was made, for example by Shahbaz and Lean (2012); Shahbaz et al., (2011). The assessment of the nexus' relationships by slicing the energy on renewable and non-renewable was carried out, for example by (Bhattacharya et al., 2016; Dogan, 2015). Finally, the Nexus has been increasingly focused on each energy source, allowing to incorporate the technology characteristics of each source and analyse its influence on economic growth, such as carried out by Ohler and Fetters, (2014) and Marques et al., (2014).

On the whole, no matters the level of detail of the energy measures, the Nexus literature is keep looking for find evidence for the four main traditional hypotheses, (i) feedback hypothesis; (ii) growth hypothesis; (iii) neutrality hypothesis; and (iv) conservation hypothesis. In short, the feedback hypothesis indicates a bidirectional relationship between energy consumption and economic growth. The growth hypothesis supports the presence of a unidirectional causal relationship running from energy consumption to economic growth. The neutrality hypothesis suggests no relationship between energy consumption and economic growth. Finally, the conservation hypothesis consists of a unidirectional relationship running from economic growth to energy consumption.

The economic growth phenomenon should not be dissociated from the problem of environmental degradation. Indeed, economic growth is correlated with environmental degradation, as shown by several studies, namely those focused on validating the Environmental Kuznets Curve (*EKC)* (e.g. Dinda, 2004; Saboori et al., 2012). The idea behind the *EKC* is that the economy of a country beginning the process of industrialisation starts to grow, and thereby raises pollution levels. In this regard, it is claimed that investment in *RES* can further support a sustainable economic growth trajectory.

Much of the literature does not incorporate an environmental approach (e. g. Bhattacharya et al., 2016; Tang et al., 2016). On contrary, authors such as Sebri, (2015); and Wang et al., (2015) consider the environment in the study of the nexus. The sustainable development target should be a project of the Humankind. Each country, at its scale, should also define as a reference to achieve that sustainable development, which must be made compatible with the energy – growth nexus. Understanding how environmental awareness interacts in the electricity mix could help policymakers in designing sustainable electricity mixes.

Modern economies, such as the French economy, with a diversified range of options regarding electricity generation, need to ascertain the way that each source interacts with economic growth, without compromising the environment. France is an interesting country to study, given that there is a strong environmental conscience, while there is a dominant electricity source which could create a substantial barrier to the diversification of the electricity mix, namely the penetration of renewables. However, the literature focused on France is scarce. Ang (2007) studied a dynamic causal relationship between *CO2* emissions, energy consumption, and output for France using a vector error-correction model (*VECM*). The author concludes that there is a robust long-run relationship, indicating that more energy consumption results in more *CO2* emissions. Ang (2007) has also shown evidence that economic growth causes *CO2* emissions and energy consumption in the long-run, and that there is a unidirectional causality from energy to growth in the short-run. Yoo and Ku (2009), uncovered an existence of a unidirectional causality running from economic growth to nuclear energy consumption. Using a different approach Apergis and Payne (2010), obtained evidence of a bidirectional causality between nuclear energy consumption and economic growth in the short-run. It was also proved the presence of a unidirectional causality running from nuclear energy consumption to economic growth in the long-run. Contradicting these findings, Chu and Chang (2012) pointed out that they could not prove a causal relation between nuclear energy and economic growth, finding thus evidence for the neutrality hypothesis.

Recently, Ben et al. (2015) found short-run bidirectional causality between gross nuclear electricity production and primary electricity production. They also noted a short-run unidirectional causality resulting from the gross production of hydropower and the wind, jointly with the main production of electricity. The authors confirmed the feedback hypothesis between the nuclear source and economic growth in the short-run. Ben et al. (2015) also confirmed that economic growth has a significant effect on increasing renewable energy consumption. However, the authors do not focus on the role each source plays within the internal adjustment of the electricity system and with economic growth. In short, the study of the nexus on France is scarce, and not consensual regarding the outcomes. The analysis of the each source within the electricity system remains largely undone, namely by enrich the nexus with the analysis of the dynamics of the interactions between the several energysources.

3. France's electricity system

The French electricity system is composed of several sources of generation, namely coal, oil,

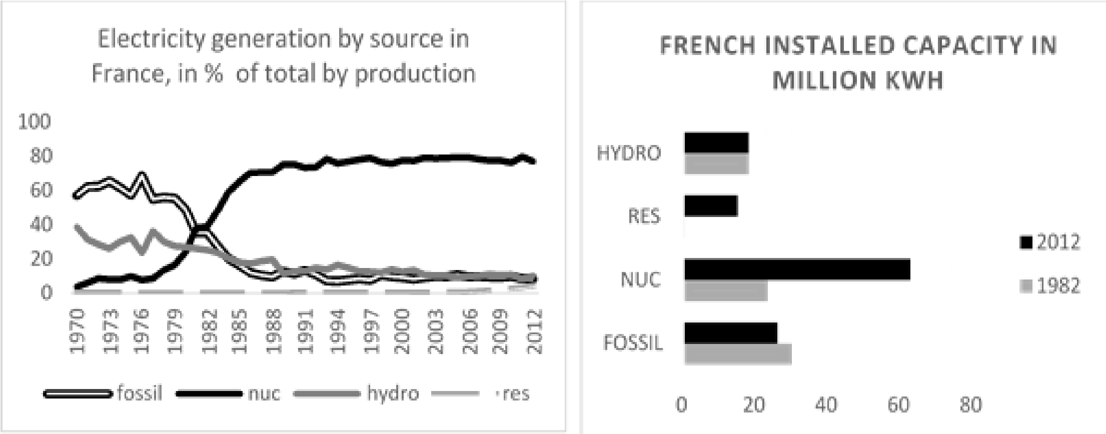

Fig. 1 - French electricity generation and installed capacity, Source: World Bank.

gas, nuclear, wind, solar, hydro and other RES (tidal and thermal). The electricity system is managed by the RTE (*Réseau de Transport d'Électricité*) which is the Transmission System Operator (TSO). This diversified electrical system has suffered several changes over time. Increases in the population and industrial activity have led France to focus on the nuclear energy (Ben et al., 2015).

In 1982 a turning point occurred when the production from nuclear source surpassed that from fossil fuel. Nuclear sources began to substitute fossil sources. From 1982 to 1997, France boosted its nuclear installed capacity from 23 to the 60 million kWh achieved in 1997 (International Energy Agency (IEA), 2009). Regarding fossil sources, there was a reduction of the installed capacity, as shown in Fig. 1.

Managing an electricity system is quite complex. To obtain the correct use of all sources, various measures and policies are applied to each energy source. As a European Union member, France is obligated to comply with the renewables quota within its domestic electricity mix. As consequence, the installed capacity of RES has increased greatly (Fig. 1). In 1996, the installed capacity of *RES* was equivalent to almost 5.8 % of that using fossil fuel sources, in 2012, the installed capacity of *RES* reached 57%.

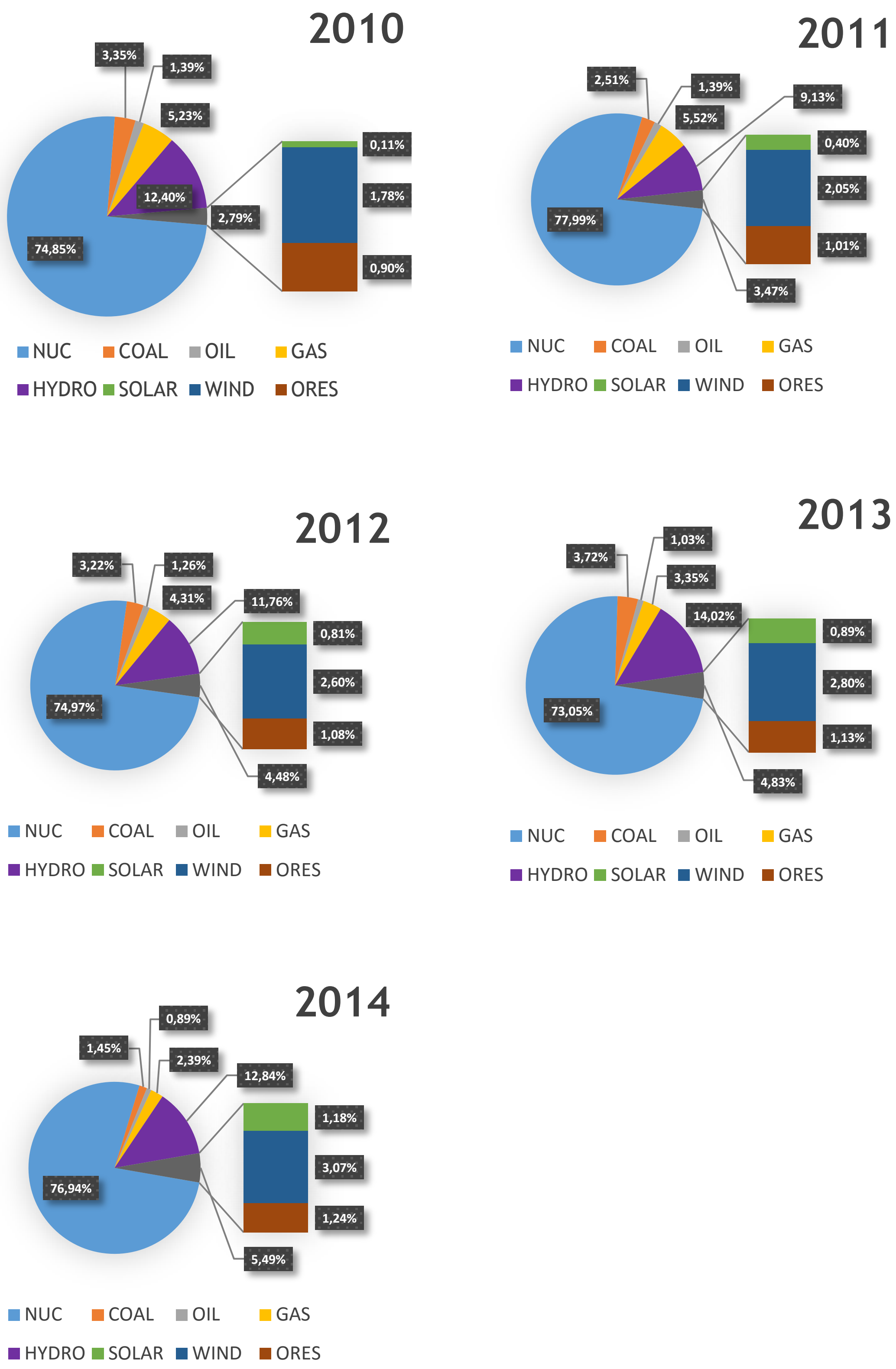

Fig. 2 - Electricity production by source.

The Fig. 2 shows the percentage of each source to the total annual electricity production, December of 2014 is not included. It should be highlighted the strong position of the nuclear source in the electricity mix, and the constant increase of electricity produced by renewable sources (solar, wind and other renewables). The nuclear source has been the most used in the French electricity production system, but, with the large renewable energy deployments, the French electricity systems have to implement policies to regulate them. For instance, renewable sources have priority over the other sources of electricity production. Consequently, the electricity produced by them is instantly introduced in the grid to fulfil the demand. Therefore, this policy forces to decrease the production from other sources, namely the fossil fuels sources, to avoid overload the electricity grid, i.e. the substitution effect between the electricity generation sources.

Due to pumping, electricity cross-border markets and other mechanisms, the electricity systems has been efficiently managing the surplus of electricity. Indeed, when the grid has an excess of electricity, water is pumped to the dams. Consequently, when the demand is high, and the renewable energies production is low, the water pumped is used to produce electricity. Electricity trading is used when there is an excess of production, and there is demand aboard, the electricity is sold. The opposite relation can occur, if the electricity price is very low, it can be more profitable to import instead of produce. Also, when the electricity price is almost zero, the cross-border countries buy to do the pumping.

France is well positioned in Europe, it has several physic frontiers, with allows to establish several international grids connections. France Imports and exports electricity to the following countries: United Kingdom, Belgium, Germany, Switzerland, Italy and Spain.

Focusing once again on the main source of production, France is facing a difficult challenge. The future of the nuclear source is uncertain, a life expectancy of a nuclear reactor is 40 years (International Energy Agency (IEA), 2009), France started their nuclear program in 1970. Some of the reactors that are operating have overcome their life expectancy. France was forced to obtain a ten year extension license, which allows the use of oldest reactors. Extending the licences is a short-term solution, France will have to build new nuclear power plants our increase the installed capacity of other sources of production. However, France will have at is disposable the new reactors (Generation 3+) in 2020. This technologic upgrade brings significant improvements in safety, comparing with the generation 3 reactors current in use (International Energy Agency (IEA), 2009).

Due to the nuclear licencing problem, the French electricity systems has at is disposal several solutions to maintaining the installed capacity and to satisfy the demand with low CO2 emissions: (i) the extension of nuclear program; (ii) the increase of the installed capacities of renewable energy sources, and increase the installed capacity of natural gas plants, the most flexible and less pollutant fossil fuel, to back up the renewable energies and unstable electricity demand.

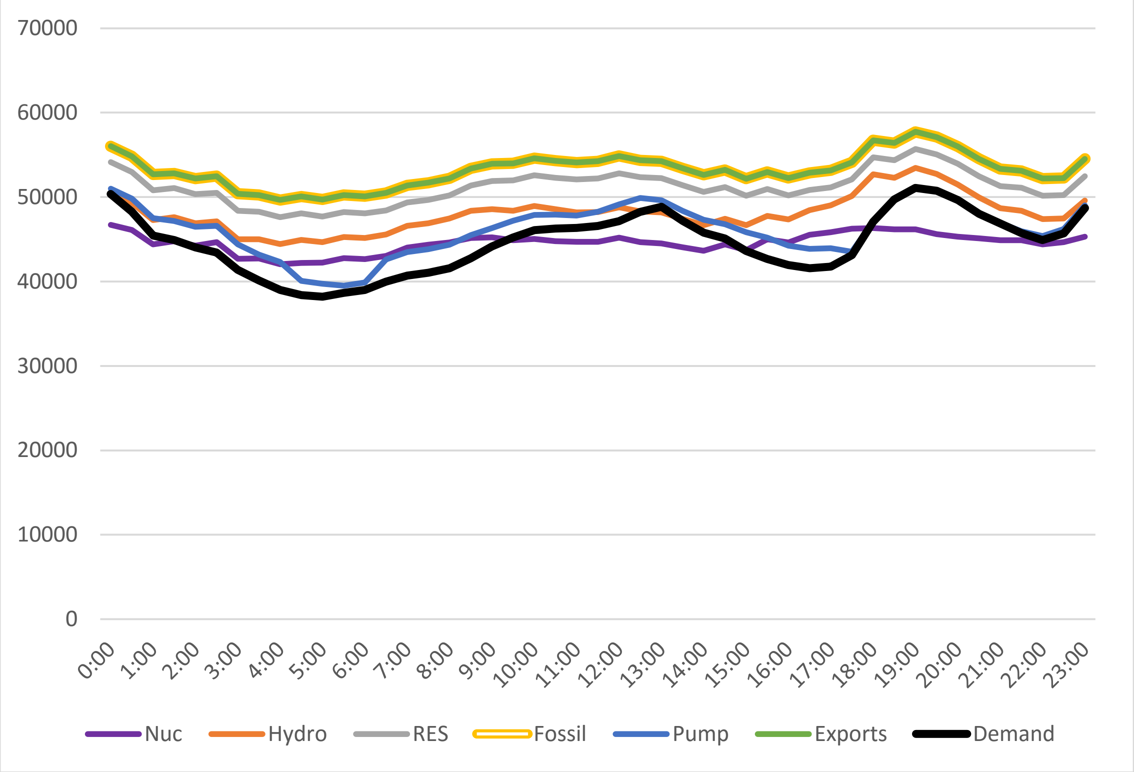

Fig. 3 – Electricity production diagram (1/11/2014), Source: RTE

Focusing on the remaining sources of production, France resorts to them when the nuclear source is not capable of fulfilling the demand (fig. 3). This indicates that some sources assume a dual position of baseload and backup, others only a backup function. The production from the hydroelectric source assumes a dual position, has a stable production together with the nuclear source, but when the peak load rises, there is an accretion of production following the rise of the demand. As backup source France utilises gas. This backup source as an ability of rapid response, fulfilling the reminiscent demand.

The TSO predicts the electricity demand, still this prediction is not entirely accurate, due to this France, as to maintain several sources with the ability of rapid increase our decrease the production to preserve the stability of the system.   Maintaining several sources of production France can guarantee their energy security (Valdés Lucas et al., 2016). Still, maintain several sources increases the costs, financial and environmental.

4. Data and Methodology

On this section, the data used in the study will be presented and the methodology applied will be described and supported.

4.1 Data

This study uses two different time spans for France. In the first one, monthly data from January 2010 till November 2014 was used, the longest period available at January of 2015. The monthly data constitutes the main reference period in the empirical estimation. The second one comprises annual data from 1970 till 2012 used to perform the robustness of the obtained results. This decision to use the first as the main reference period and the second as the robustness period was taken for two reasons. First, using data gathered monthly allows for a larger number of observations than annual data. Second, monthly data permits analysis of individual electricity sources, which is impossible using annual data, even for a reasonable span of time, given that there are available disaggregated data by source, only for a few years. All the data available in January 2015 was used.

The monthly data was retrieved from RTE, INSEE (Institut National de la Statistique et des Études Économiques), and ENTSO-E (European Network of Transmission System Operators). The definition, descriptive statistics and source of each one variable under study are shown in Table 1. Hereafter, the operators “L” and “D” denote the natural logarithm and the first differences of the variables, respectively.

Table 1 – Summary Statistics

Variable	Definition	Mean	Max.	Min.	Std. Dev.	JB	Obs.	Source
LIPI	Industrial production index (IPI).	4.5971	4.7449	4.2654	0.0969	85.4022	59	INSEE
LCOAL	Electricity from coal source.	6.9653	7.9820	4.3694	0.7439	21.6332	59	ENTSO-E
LOIL	Electricity from oil source.	6.2224	7.2341	5.6276	0.3841	7.3619	59	ENTSO-E
LGAS	Electricity from gas source.	7.3180	8.4972	6.0890	0.7515	3.9477	59	ENTSO-E
LFOSSIL	Electricity from fossil source.	8.0836	9.0826	6.7901	0.6044	2.1276	59	RTE
LHYDRO	Electricity from hydroelectric.	8.5658	9.0600	8.0765	0.2553	3.4490	59	RTE
LNUC	Electricity from nuclear source.	10.4298	10.6886	10.1872	0.1202	2.8628	59	RTE
LWIND	Electricity from wind.	6.9791	7.8179	6.1903	0.3571	0.9247	59	RTE
LSOLAR	Electricity from photovoltaic.	5.2722	6.6337	2.5649	1.0345	5.9561	59	RTE
LORES	Electricity from other renewable sources.	6.1656	6.4016	5.8749	0.1330	2.2805	59	RTE
LRES	Electricity from renewable sources.	7.5187	8.0973	6.8638	0.2872	1.7385	59	RTE
LPUMP	Electricity consumption from pumping.	6.3597	6.6522	5.9135	0.1488	4.9514	59	RTE
LECO2	CO2 emissions from electricity generation.	7.6085	8.5610	6.5510	0.5306	2.0799	59	RTE

Notes: All the variables are converted in natural logarithms; (Max.), maximum value; (Min.) Minimum value; (JB) Jarque-Bera statistic

The variables are based on those found in the literature (Apergis et al., 2016; Cowan et al., 2014; Marques et al., 2016), except the *CO2* emissions due to their unusual monthly frequency, which will be explained below. In short, the relationship between the electricity generation mix, the environment and growth was studied using variables of economic growth (Industrial Production Index – IPI - as proxy); electricity mix (several electricity sources, renewables and non-renewables); and environment (*CO2* emissions). The variable *ECO2* emissions deserves a special comment, given that it is usually unavailable with a monthly frequency. Fortunately, RTE computed this variable for the entire first period of analysis. Please note that the *ECO2* emissions are only those related to electricity generation. As such, considering the eventual existence of the collinearity problem between the variables, the fossil sources (coal, oil, gas and aggregated one) should not be used with that for *ECO2* emissions simultaneously confirmed by a high *VIF* of 54. As such, two separate models were specified, one controlling for fossil sources and the other controlling for CO2 emissions.

4.2 Methodology

The analysis adheres to the following path. First, a visual inspection of the series was carried out, looking for potential disturbances in the data. Second, the statistical properties of the series was assessed by providing the unit root tests of Augmented Dickey–Fuller (ADF) (Dickey and Fuller, 1979), Phillips–Perron (PP) (Phillips and Perron, 1988) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) (Shin et al., 1992).

Third, the ARDL bounds test approach suggested by Pesaran and Shin (1999), was carried out. This method is increasingly used in the literature focused on the nexus (e.g. Bildirici and Kayıkçı, (2013); Bölük and Mert, (2015); C. Bento and Moutinho, (2016)), which is a consequence of its versatility for handling specific characteristics of the data. Indeed, this approach has several main advantages, namely: (i) the ability to analyse both the short- and long-run relationships separately through semi-elasticities and elasticities respectively; (ii) capacity to use variables with a different order of integration, once guaranteed that they have an integration order less than two, i.e. I(2); (iii) the ability to support endogeneity; and (iii) being robust in the presence of "one-zero" dummies. Moreover, such as shown by Jouini (2015), the robustness of the ARDL model provides evidence of a possible directional causal relationship.

Fourth, the quality and goodness-of-fit of the models were assessed through a battery of diagnostic tests, namely Jarque–Bera normality test (Jarque and Bera, 1980), Breusch–Godfrey serial correlation LM test (Breusch, 1978), ARCH test for heteroscedasticity (Bollerslev, 1986), and Ramsey RESET test for functional misspecification (Ramsey, 1969). Moreover, the stability of the coefficients was assessed by providing the CUSUM and CUSUM of Squares tests (Nyblom, 1989). Fifth, to check the existence of cointegration, i.e. the long-run relationship, the ARDL bounds test suggested by Pesaran et al. (2001) was performed. Finally, beyond of all these procedures, a specific section was devoted to the robustness check of the findings. In order to do that, a different (annual) data frequency was used. Once again, the quality of the models was exhaustively tested and the findings compared and discussed.

The general form of the unrestricted error correction model (UECM) of the ARDL, may be specified as follows:

$$\Delta X_t = \alpha_0 + \alpha_1 TREND + \alpha_2 \Delta Z_t + \alpha_3 \sum_{p=1}^{k} X_{t-p} + \alpha_4 \sum_{p=1}^{k} Z_{t-p} + \varepsilon_t , \quad (1)$$

where, the Δ operator stands for the first differences, ΔX_t is a vector of dependent variables; ΔZ_t is a vector of explanatory variables, α_{2i} represents the semi-elasticities of the explanatory variables, α_{3i} represents the error correction mechanism (ECM), α_{4i} show us the long-run coefficients, and the ε_t shows the disturbance terms.

5. Results

Following the aforementioned path, the visual inspection of the series reveals disturbances coinciding with the eighth month (August) in the *IPI* series. This occurrence corresponds to the well-known vacation period when the country's industrial activity slows down. As such, a seasonal dummy (ID08) was used for the eighth month in the IPI models. To assist the reader, the models in which the subscript M refers to the Monthly frequency data, are named as follows:

- $Model_M$ – I_FOSSIL, dependent variable FOSSIL;
- $Model_M$ – II_HYDRO, dependent variable HYDRO;
- $Model_M$ – III_NUC, dependent variable NUC;
- $Model_M$ – IV_RES, dependent variable RES;
- $Model_M$ – V_IPI-A, dependent variable IPI, FOSSIL aggregated;
- $Model_M$ – VI_IPI-B, dependent variable IPI, RES aggregated;
- $Model_M$ – VII_IPI-C, dependent variable IPI;
- $Model_M$ – VIII_IPI_D, dependent variable IPI, inclusion of CO2;
- $Model_M$ – IX_HYDRO_D, dependent variable HYDRO, inclusion of CO2;
- $Model_M$ – X_NUC_D, dependent variable NUC, inclusion of CO2 emissions;
- $Model_M$ – XI_RES_D, dependent variable RES, inclusion of CO2 emissions;

Regarding the *$Model_M$ - III_NUC* and the *$ModeL_M$ - X_NUC_D*, the data on the planned maintenance of the grid and of maintenance in the remaining sources, occurring in January (*ID01*) and December (*ID12*), were observed in the visual inspection both of the series and of the residuals. As such, two "one-zero" dummies (impulse dummies) were included. Such as referred previously, the ARDL model is not affected by the inclusion of a “one-zero” dummy, as noted by Hoque and Yusop (2010).

Continuing on this path, the unit root tests (Table 2) show no unanimity for all the variables. In some cases, they point to series with an order of integration I(0), I(1) or even borderline I(0)/I(1). However, the tests unequivocally show that none of the variables are I(2). This fact is not compromising the use of the ARDL approach.

Table 2 - Unit Root Test (monthly frequency)

	ADF			PP			KPSS	
	a)	b)	c)	a)	b)	c)	a)	b)
LIPI	-6.7688***	-7.7415***	-0.1246	-7.8863***	-7.7419***	-0.1024	0.0350	0.1885
DLIPI	-14.778***	-14.403***	-14.3458***	-28.6622***	-28.867***	-29.2595***	0.1885***	0.3707*
LECO2	-4.8550***	-3.6548***	-1.4867	-3.4085**	-3.4466**	-0.4746	0.0473	0.2533
DLECO2	-7.4351***	-7.3300***	-7.0635***	-6.7617***	-6.7966***	-6.8577***	0.0416	0.0668
LCOAL	-3.7042**	-3.6698***	-0.5919	-3.8106**	-3.7575***	-0.6092	0.1081	0.2371
DLCOAL	-7.9109***	-7.9807***	-8.0495***	-8.7730***	-8.9263***	-9.0070***	0.0676	0.0780
LFOSSIL	-5.8965***	1.4733	-2.2467**	-3.2747*	-3.1773**	-0.4806	0.0482	0.4248*
DLFOSSIL	-7.5253***	-7.0615***	-6.3385***	-5.6414***	-5.6654***	-5.7201***	0.0358	0.0532
LGAS	-7.7519***	-0.7807	-0.9213	-3.1648	-3.1234**	-0.4536	0.0307	0.4610*
DLGAS	-5.8548***	-5.7853***	-8.7048***	-5.2338***	-5.2447***	-5.2995***	0.0348	0.0542
LHYDRO	-4.8631***	-4.6941***	-0.2283	-2.8085	-2.8683*	-0.5792	0.1133	0.2162
DLHYDRO	-6.8975***	-6.9719***	-7.0326***	-7.9352***	-8.0639***	-8.3043***	0.5000***	0.5000**
LNUC	-6.1864***	-5.9995***	0.2287	-2.9611	-3.0469**	-0.1804	0.0275	0.0522
DLNUC	-6.7287***	-6.8189***	-6.9388***	-5.5321***	-5.5774***	-5.6522***	0.0347	0.0573
LOIL	-6.6714***	0.2014	-1.5445	-3.8462**	-3.8431***	-0.6200	0.0393	0.4462*
DLOIL	-7.2624***	-7.1366***	-6.8432***	-7.4506***	-7.4706***	-7.5392***	0.0457	0.0924
LORES	-5.4013***	-1.3651	1.1787	-7.5439***	-3.1806**	1.5558	0.0802	0.9877***
DLORES	-10.715***	-10.3261***	-7.8997***	-40.166***	-40.554***	-20.3038***	0.1436*	0.1874
LPUMP	-5.5794***	-4.5302***	0.6503	-5.3377***	-4.5279***	0.5068	0.0756	0.7232**
DLPUMP	-7.0803***	-7.1563***	-7.1759***	-29.055***	-23.414***	-19.7809***	0.2054**	0.3228
LRES	-4.8422***	-1.8196	0.5705	-4.9796***	-2.6105*	0.7952	0.1416*	0.8137***
DLRES	-11.539***	-11.6394***	-11.6853***	-12.331***	-12.4313***	-12.3204***	0.0396	0.0644
LSOLAR	-2.8382	-5.8124***	-0.2190	-2.7745	-2.7276*	0.3201	0.1728**	0.8786***
DLSOLAR	-6.4271***	-6.9594***	-3.7104***	-3.8299**	-3.6707***	-3.7104***	0.0319	0.1793
LWIND	-4.3063***	-3.7086***	0.13491	-4.3793***	-3.7928***	0.2622	0.0730	0.5764**
DLWIND	-9.8578***	-9.9540***	-10.0352***	-9.8578***	-9.9540***	-10.0352***	0.0260	0.0281

Notes: a) Trend and intercept; b) Intercept; c) None; ***,**,*, represents 1%,5% and 10% of significance respectively; ADF, stands for Augmented Dickey–Fuller test; PP: stands for Phillips–Perron test; KPSS: stands for Kwiatkowski–Phillips–Schmidt–Shin; D stands for the first differences;

The ARDL estimations provide both the coefficients and the ECM (Table 3). All the estimations fulfil all the diagnostic tests (Table 3). The Jarque–Bera (JB) confirms the normality behaviour of the residuals. The Breusch–Godfrey LM and the ARCH tests are rejecting the presence of serial correlation and heteroscedasticity to the third order, respectively. The RESET test confirms the correct functional form of all models. The CUSUM and CUSUM of squares tests (Fig. 4) support that the models are stable for the entire period under analysis[1].

The coefficients of the variables, in first differences, refer to the short-run, and they can be directly interpreted as semi-elasticities. For the long-run, the estimated coefficients were

[1] Please note that the time spans of these two tests are not fully coincident due to the use of impulse dummies.

used to compute the elasticities, by dividing them by the coefficient of the ECM, and then multiplying by -1. Semi-elasticities and elasticities are displayed in Table 3 and Table 4, respectively. Electricity sources were included in the estimations in both aggregated and disaggregated forms. This option is revealed to be suitable, not only to enrich the analysis but essentially to capture the specific effects of each electricity source. Indeed, results reveal that the distinct technological characteristics of each source could provoke different effects both on the economy as a whole, but also within the electricity system, which is a dynamic system.

Overall, the results reveal consistency, both with the literature and with that of the observed of energy policies pursued in France. All the estimations displayed a negative and statistically significant adjustment speed (ECM). They reveal a slow and median speed of adjustment throughout all the models, with the exception of the IPI models. Here a high adjustment speed of circa 91% was found. Both $Model_M$ – *III_NUC* and $Model_M$ – *X_NUC_D*, present a lower speed of adjustment, as expected.

Table 3 - ARDL models and coefficients

	$Model_M$ - I_FOSSIL	$Model_M$ - II_HYDRO	$Model_M$ - III_NUC	$Model_M$ - IV_RES	$Model_M$ - V_IPI_A	$Model_M$ - VI_IPI_B	$Model_M$ - VII_IPI_C	$Model_M$ - VIII_IPI_D	$Model_M$ - IX_HYDRO_D	$Model_M$ - X_NUC_D	$Model_M$ - XI_RES_D
DLIPI	0.8703***	0.3950**	0.2763***	-	-	-	-	-	-	0.3266***	-
DLFOSSIL	-	-	-	-	0.0579***	-	-	-	-	-	-
DLCOAL	-	-0.0910**	-	-	-	0.0306**	0.0329***	-	-	-	-
DLOIL	-	0.1872**	-	0.1139*	-	-	-	-	-	-	-
DLGAS	-	-0.2232***	0.0428***	-	-	-	-	-	-	-	-
DLHYDRO	-0.9708***	-	-	0.2330**	-	-	-	-	-	-0.0683**	0.1852*
DLNUC	-	-	-	-	0.3239***	0.2438***	0.2687***	0.3443***	-	-	-
DLRES	-	-	-	-	-	-	-	-	-	-	-
DLWIND	0.3011*	0.2229***	-0.0590***	-	-0.0743***	-	-	-0.0729***	0.2954***	-	-
DLSOLAR	-0.5668***	-0.2086***	-0.0653***	-	0.0540*	-	-	0.0508*	-	-0.1149***	-
DLORES	0.6668**	-	0.3489***	-	-	-	-	-	-	0.4642***	-
DLPUMP	-	-	0.1001***	0.2454**	-	-	-	-	-	-	0.3859***
DLECO2	-	-	-	-	-	-	-	0.0516**	-0.1396***	-	-
LIPI(-1)	-	0.5218***	0.3559***	-	-0.9111***	-0.8718***	-0.8840***	-0.9124***	-	0.4266***	-
LFOSSIL(-1)	-0.3748***	-	-	-	0.0381*	-	-	-	-	-	-
LCOAL(-1)	-	-	-	0.0633**	-	-	-	-	-	-	-
LOIL(-1)	-	-	-	0.2188**	-	-	-	-	-	-	-
LGAS(-1)	-	-0.1614***	-	-0.0908*	-	-0.0430***	-	-	-	-	-
LHYDRO(-1)	-0.4232**	-0.4346***	-	-	-	-	-	-	-0.4440***	-0.0458*	-
LNUC(-1)	0.4063**	-	-0.3004***	0.4193***	0.3931***	0.4675***	0.4380***	0.3990***	-0.8557***	-0.2719***	0.3126**
LRES(-1)	-	-	-	-0.7761***	-	-0.0700***	-	-	-	-	-0.8082***
LWIND(-1)	0.4911***	0.4606***	-0.0805***	-	-0.1623***	-	-0.0814***	-0.1609***	0.5246***	-	-
LSOLAR(-1)	-0.1909***	-0.1337***	-0.0230**	-	0.0364***	-	0.0173***	0.0324***	-0.0896***	-0.0456***	-
LORES(-1)	-	-	0.3512***	-	-	-	-	-	-	0.4240***	-
LPUMP(-1)	-	-	-	-	0.1174**	-	-	0.1139**	-	-0.1196***	0.2760*
LECO2(-1)	-	-	-	-	-	-	-	0.0377*	-	-0.0470***	0.0987**
TREND	-	-	-	0.0113***	-	-	-	-	-	-	0.0108***
C	-	-	-	-	-	-	-	-	9.5325***	-	-
ECM	-0.3748***	-0.4346***	-0.3004***	-0.7761***	-0.9111***	-0.8718***	-0.8840***	-0.9124***	-0.4440***	-0.2719***	-0.8082***
Time Dummies:											
ID01	-	-	0.1022***	-	-	-	-	-	-	0.0882***	-
ID12	-	-	0.1357***	-	-	-	-	-	-	0.1227***	-
ID08	-	-	-	-	-0.3098***	-0.3016***	-0.2980***	-0.3080***	-	-	-
Diagnostic Tests:											
ARCH	[0.3408](1)	[0.9473](1)	[1.7630](1)	[0.4768](1)	[0.3248](1)	[0.0549](1)	[0.6182](1)	[0.2523](1)	[0.5697](1)	[1.8568](1)	[0.5289](1)
	[1.0064](2)	[0.7133](2)	[0.4948](2)	[0.7970](2)	[0.7306](2)	[0.9769](2)	[0.5917](2)	[0.7273](2)	[0.3171](2)	[0.9565](2)	[0.9192](2)
	[1.0227](3)	[1.5470](3)	[0.9707](3)	[0.7526](3)	[0.8681](3)	[0.6193](3)	[0.3628](3)	[0.4885](3)	[0.3172](3)	[0.8548](3)	[0.7319](3)
LM	[0.2593](1)	[0.8457](1)	[0.9697](1)	[1.9232](1)	[0.1101](1)	[0.4313](1)	[0.7520](1)	[0.3391](1)	[1.4767](1)	[0.6187](1)	[0.5277](1)
	[0.2879](2)	[0.4143](2)	[0.5367](2)	[0.9848](2)	[0.0605](2)	[0.2159](2)	[0.3685](2)	[0.1840](2)	[1.3712](2)	[0.5240](2)	[0.8206](2)
	[0.1913](3)	[0.8470](3)	[0.8625](3)	[0.6470](3)	[0.8681](3)	[1.1405](3)	[1.0804](3)	[0.8369](3)	[1.1423](3)	[0.5681](3)	[0.8857](3)
JB	[0.3031]	[0.3060]	[2.4747]	[2.0181]	[2.1572]	[0.7315]	[0.4709]	[2.0783]	[1.0638]	[0.1618]	[1.1116]
RESET	[0.4559]	[0.5468]	[0.0180]	[0.0231]	[0.1231]	[0.5683]	[0.1077]	[0.0778]	[0.0118]	[0.9871]	[1.4763]

Notes: The IPI models includes fossil Sources in aggregated form (*IPI_A*); *RES* aggregated (*IPI_B*) ; *RES* separated (*IPI_C*); Inclusion of *CO2* emissions and exclusion of fossil sources (*IPI_D; HYDRO_D; NUC_D; RES_D*); ***,**,*, represents 1%,5% and 10% of significance respectively; ARCH: test for heteroscedasticity (Bollerslev, 1986)(Bollerslev, 1986); JB: Jarque–Bera normality test (Jarque and Bera, 1980); LM: Breusch–Godfrey serial correlation LM test (Breusch, 1978); RESET: Ramsey RESET (Ramsey, 1969); In (.) lag order; in [.] F-statistic value

Attending to the four traditional hypotheses vastly defined in the energy-growth nexus literature, in this work the proven relationships for France can be summarised as follows: (i) for the dominant nuclear source, statistical evidence was found for the feedback hypothesis, both on the short- and long-run; (ii) for solar and wind sources proof of the growth hypothesis was found, both on the short- and long-run; and (iii) for fossil sources evidence was found for the feedback hypothesis on the short-run. Moreover, statistical evidence for CO2 emissions leading towards the IPI, on the short-run was learnt. It is worthwhile to note that the proof of the feedback hypothesis constitutes and an additional sign of endogeneity, which reinforce the adequacy of the use of the ARDL approach.

Table 4 – Elasticities

	$Model_M$ - *I_FOSSIL*	$Model_M$ - *II_HYDRO*	$Model_M$ - *III_NUC*	$Model_M$ - *IV_RES*	$Model_M$ - *V_IPI_A*	$Model_M$ - *VI_IPI_B*
LIPI(-1)	-	1.2004***	1.1846***	-	-0.9111***	-0.8718***
LFOSSIL(-1)	-0.3748***	-	-	-	0.0418*	-
LCOAL(-1)	-	-	-	0.0816*	-	-
LOIL(-1)	-	-	-	0.2819**	-	-
LGAS(-1)	-	-0.3714***	-	-0.1170*	-	-0.0493***
LHYDRO(-1)	-1.1289**	-0.4346***	-	-	-	-
LNUC(-1)	1.0839***	-	-0.3004***	0.5402***	0.4315***	0.5363***
LRES(-1)	-	-	-	-0.7761***	-	-0.0803***
LWIND(-1)	1.3102***	1.0596***	-0.2681***	-	-0.1781***	-
LSOLAR(-1)	-0.5093***	-0.3078***	-0.0767***	-	0.0400***	-
LORES(-1)	-	-	1.1690***	-	-	-
LPUMP(-1)	-	-	-	-	0.1288**	-
LECO2(-1)	-	-	-	-	-	-
ECM	-0.3748***	-0.4346***	-0.3004***	-0.7761***	-0.9111***	-0.8718***

	$Model_M$ - *VII_IPI_C*	$Model_M$ - *VIII_IPI_D*	$Model_M$ - *IX_HYDRO_D*	$Model_M$ - *X_NUC_D*	$Model_M$ - *XI_RES_D*
LIPI(-1)	-0.8840***	-0.9124***	-	1.5686***	-
LFOSSIL(-1)	-	-	-	-	-
LCOAL(-1)	-	-	-	-	-
LOIL(-1)	-	-	-	-	-
LGAS(-1)	-	-	-	-	-
LHYDRO(-1)	-	-	-0.4440***	-0.1686*	-
LNUC(-1)	0.4954***	0.4372***	-1.9269***	-0.2719***	0.3868***
LRES(-1)	-	-	-	-	-0.8082***
LWIND(-1)	-0.0921***	-0.1764***	1.1813***	-	-
LSOLAR(-1)	0.0195**	0.0355***	-0.2019***	-0.1677***	-
LORES(-1)	-	-	-	1.5590***	-
LPUMP(-1)	-	0.1248**	-	-0.4399**	0.3415*
LECO2(-1)	-	0.0414*	-	-0.1728***	0.1221**
ECM	-0.8840***	0.9124***	-0.4440***	-0.2719***	-0.8082***

Notes: The *IPI* models includes fossil Sources in aggregated form (*IPI_A*); *RES* aggregated (*IPI-B*); *RES* separated (*IPI_C*); Inclusion of CO2 emissions and exclusion of fossil sources (*IPI_D; HYDRO_D; NUC_D; RES_D*); ***,**,*, represents 1%, 5% and 10% of significance respectively

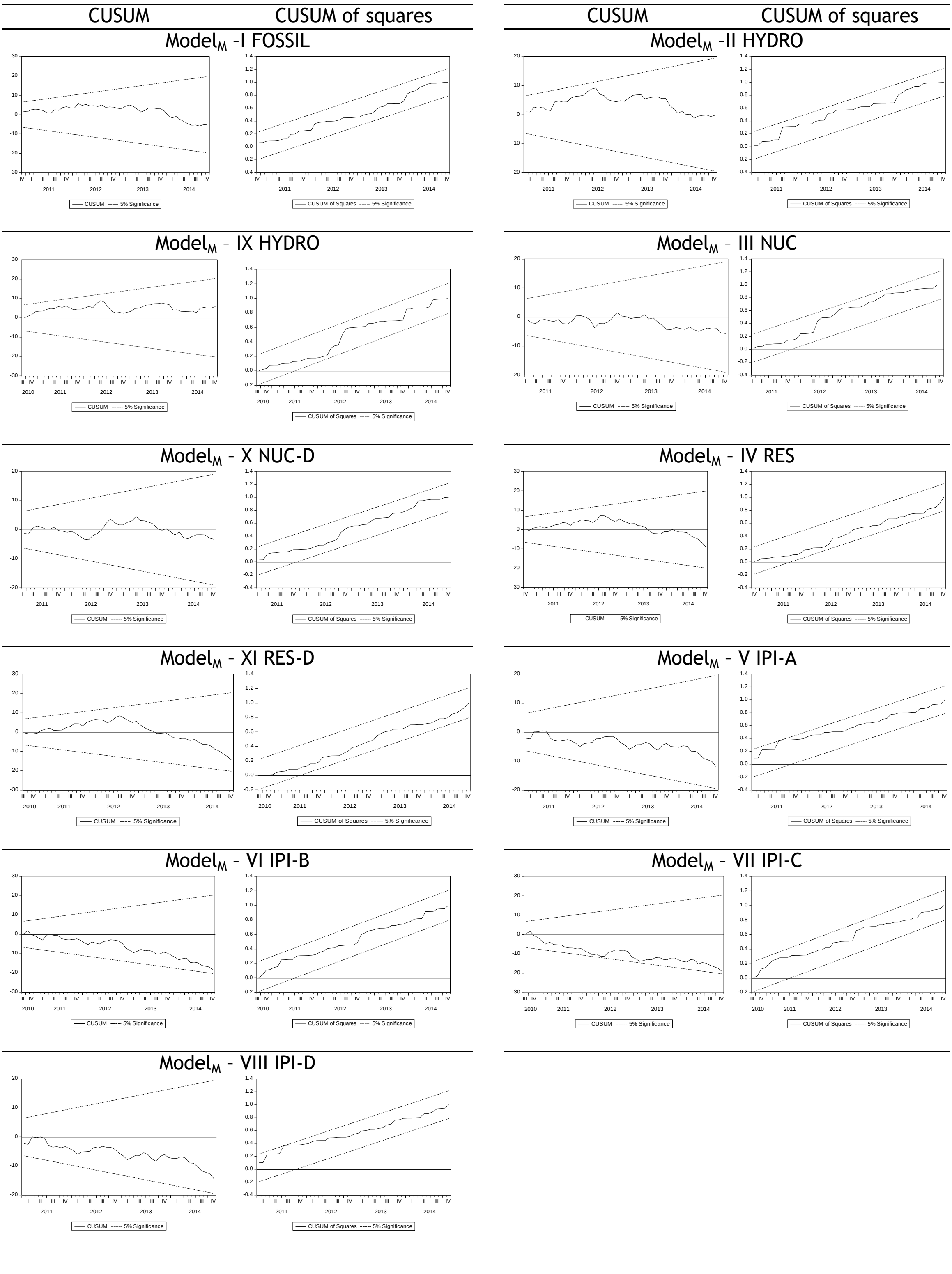

Fig. 4 – Tests of CUSUM, CUSUM of Squares

Keep going along the defined path, the ARDL bounds test to appraise the presence of cointegration relationships was carried out. The null hypothesis of the ARDL bounds test proposed by Pesaran et al. (2001), predicts the no-cointegration, i.e. the long-run coefficients are equal to zero.

Table 5 – ARDL Bounds Test

	Model$_M$ - I_FOSSIL	*Model$_M$ - II_HYDRO*	*Model$_M$ - III_NUC*	*Model$_M$ - IV_RES*	*Model$_M$ - V_IPI-A*	*Model$_M$ - VI_IPI-B*
F-Stat.	3.1250*	11.1068***	9.5489***	10.9201***	38.2829***	39.9907***
K	4	4	4	4	5	3
Bottom	1.9	3.07	3.07	4.4	2.82	3.42
Top	3.01	4.44	4.44	5.72	4.21	4.84
	Model$_M$ - VII_IPI_C	*Model$_M$ - VIII_IPI_D*	*Model$_M$ - IX_HYDRO_D*	*Model$_M$ - X_NUC_D*	*Model$_M$ - XI_RES_D*	
F-Stat.	40.0008***	37.0580***	15.5496***	7.1485***	11.6482***	
k	3	5	3	6	3	
Bottom	3.42	2.82	4.29	2.66	5.17	
Top	4.84	4.21	5.61	4.05	6.36	

Notes: The *IPI* models include fossil Sources in aggregated form (*IPI_A*); *RES* aggregated (*IPI_B*); *RES* separated (*IPI_C*); Inclusion of *CO2* emissions and exclusion of fossil sources (*IPI_D; HYDRO_D; NUC_D; RES_D*); k, represents the number of long-run variables; ***,*, represents 1% and 10% of significance respectively;

The critical values were provided by Pesaran et al. (2001). For all the models, the reference values correspond to each model's characteristics, with the exception of the *Model$_M$ – IV_RES* and *Model$_M$ – XI_RES_D*, where the unrestricted trend and intercept critical values were used. The results of the ARDL bounds test (Table 5) rejects the null hypothesis, revealing the presence of cointegration among the variables, this means that the variables have a long-run relationship.

6. Robustness check

As an additional proof of the robustness of the models, a new framework based on the annual data is used, as stated above. Therefore, identical models, with some required adaptations, were estimated under this new data frequency. After that, the results were compared with those from the monthly data frequency. The time span for the annual data is 1970 to 2012 (Table 6). Please remember that for the annual data frequency only aggregated information for some sources are available. Table 6 summarises the descriptive statistics and sources of the variables used in the robustness section.

Table 6 – Summary Statistics

	Definition	Mean	Max.	Min.	Std. Dev.	JB	Obs.	Source
LGDP	Gross Domestic Production, constant prices of 2005	28.0825	28.4417	27.5194	0.2709	2.5525	43	World bank's, development indicator database
LFOSSIL	Electricity from fossil sources	24.2987	24.9945	23.5745	0.3529	2.0926	43	Calculated using data from World bank's, development indicator database
LCOAL	Electricity from coal source	24.8675	25.6715	24.2313	0.4212	3.7833	43	World bank's, development indicator database
LOIL	Electricity from oil source	23.2637	25.0179	21.8929	0.9657	5.2536	43	World bank's, development indicator database
LGAS	Electricity from gas source	22.7761	24.0099	21.6045	0.7604	3.2558	43	World bank's, development indicator database
LHYDRO	Electricity from hydroelectric source	24.8441	25.0904	24.5259	0.1458	1.9078	43	World bank's, development indicator database
LNUC	Electricity from nuclear source	25.7747	26.8359	22.4656	1.3648	9.0392	43	World bank's, development indicator database
LRES	Electricity from renewable sources	21.4187	23.9348	20.2057	1.0520	4.3231	43	World bank's, development indicator database
LTCO2	CO2 emissions from all economic activity	6.0865	6.2991	5.9477	0.0995	4.7477	43	BP Statistical Review of World Energy (June 2014)
LNX	Exports over imports plus one	0.6994	0.7443	0.6419	0.0271	2.2755	43	World bank's, development indicator database

Notes: All the variables are converted in natural logarithms; (Max.), maximum value; (Min.) Minimum value; (JB) Jarque-Bera statistic

As such, six models were estimated, also resorting to the ARDL bounds test approach. Please note that the subscript $_A$ refers to the annual frequency data. Once again, in order to assist the reader, the models are named as follows:

- $Model_A$ – *I_GDP*, dependent variable *GDP*;
- $Model_A$ – *II_FOSSIL*, dependent variable *FOSSIL*;
- $Model_A$ – *III_HYDRO*, dependent variable *HYDRO*;
- $Model_A$ – *IV_NUC*, dependent variable *NUC*;

- *$Model_A$ – V_TCO2*, dependent variable *TCO2*;

- *$Model_A$ – VI_RES*, dependent variable *RES*;

Table 7 - Elasticities and semi-elasticities (annual data)

	$Model_A$-I_GDP	*$Model_A$ – II_FOSSIL*	*$Model_A$ – III_HYDRO*	*$Model_A$ – IV_NUC*	*$Model_A$ – V_TCO2*	*$Model_A$ – VI_RES*
DLRES	-	-	-	0.4512***	-	-
DLGAS	-	-	-0.2302**	-	-	-
DLNUC	-	-	-	-	-0.0463*	0.2164**
DLGDP	-	-	-	-	0.7719***	-
DLOIL	-	-	-	-	0.0877***	0.0812**
DLNX	-	-	-	-3.9468***	-	-
DLHYDRO	-	-0.3155**	-	-	-	-
DLTCO2	0.2474***	-	-	-	-	-
LFOSSIL(-1)	-	-0.3393***	-	-	-	-
LGDP(-1)	-0.5917***	1.3823***	0.6910***	0.6121**	0.1133***	-
LTCO2(-1)	0.3988***	-	1.6546***	-	-0.4108**	-
LNX(-1)	0.3995***	-	-	-12.3114***	-	25.9671***
LCOAL(-1)	-	-	-	1.7380***	-	-
LGAS(-1)	-0.0152**	-	-0.2032***	-	-	-
LOIL(-1)	-	-	-	-1.0627***	0.1235***	-
LNUC(-1)	0.0281***	-0.5427***	-	-0.1941***	-	-
LHYDRO(-1)	-	-	-0.7626***	-	-	-
LRES(-1)	-0.0741***	-	-	-	-	-0.0659***
ECM	-0.5917***	-0.3393***	-0.7626***	-0.1941***	-0.4108***	-0.0659***

Notes: ***,**,*, represents 1%, 5%, and 10% of significance level, respectively

One more time, the models were subject to both the diagnostic tests (Table A.2) and stability tests (Fig. A.1). All models verify the desired econometric properties, with the exception of the *$Model_A$ – IV_NUC*. In this model, the Jarque-Bera test rejects the null hypothesis of normality. However, by analysing the skewness and kurtosis, no significant deviation of the residuals was found. The milestones in each source were identified, and accordingly, an impulse dummy was used. Therefore, in the *$Model_A$ – IV_NUC*, two facts were considered: (i) a major nuclear accident occurred in 1980 (*ID1980*); and (ii) research and modification of nuclear source ended in 1997, (*ID1997*). Regarding the *$Model_A$ – VI_RES*, the exceptional increase in installed capacity and production in 1990 caused a disturbance (*ID1990*). By its turn, in the *$Model_A$ – I_GDP*, the international crises had an impact on *GDP*, causing a severe contraction in 2009 (*ID2009*).

Comparing the semi-elasticities and elasticities from the two frequencies of analysis, monthly (Tables 3 and 4) and annual (Table 7), similar effects for the statistically significant variables were found. This is especially true for the *$Models_A$ – I GDP*, *$Models_A$ – IV_NUC*, and *$Models_A$ – VI_RES*. For the *$Model_A$ – II_FOSSIL*, *$Model_A$ – III_HYDRO* and *$Model_A$ - V_TCO2*, some additional comments are required. Regarding the *$Model_A$ – II_FOSSIL*, the signal achieved for the longest data frequency (annual) is shown to be negative, contrary to that observed with the monthly frequency. At a first glance, this could be seen as a different outcome, but it is not actually. In fact, it is a proof of the models' adherence to reality. The installed capacity of the nuclear source and their contribution to the electricity mix after 1975 are significantly increased, provoking a substitution effect on fossil sources (such as shown in Fig. 1). This negative signal is, therefore, unexpected, but it is coherent with the dominant role played by a nuclear source in France after the mid-1970s. According to $Model_A$ – *III_HYDRO*, a special focus must be placed on *CO2* emissions. Note that, as explained above, the *CO2* data used is in a monthly frequency is not the same as that utilised in the annual data framework and, as such, is not directly comparable. The figure 5, shows the main relationships between the economic growth, electricity production and environment. Both short and long run, positive and negative effects are not differentiated on this figure. It is worth highlight the presence of a bidirectional relationship between electricity generation from a nuclear source, in the IPI and GDP. Indeed, it is an additional prove of robustness of results because the nuclear source has the highest weight in the French electricity system. Moreover, the statistical evidence of the feedback hypothesis already found with monthly data framework is also confirmed in the long-run with the use of the annual data framework.

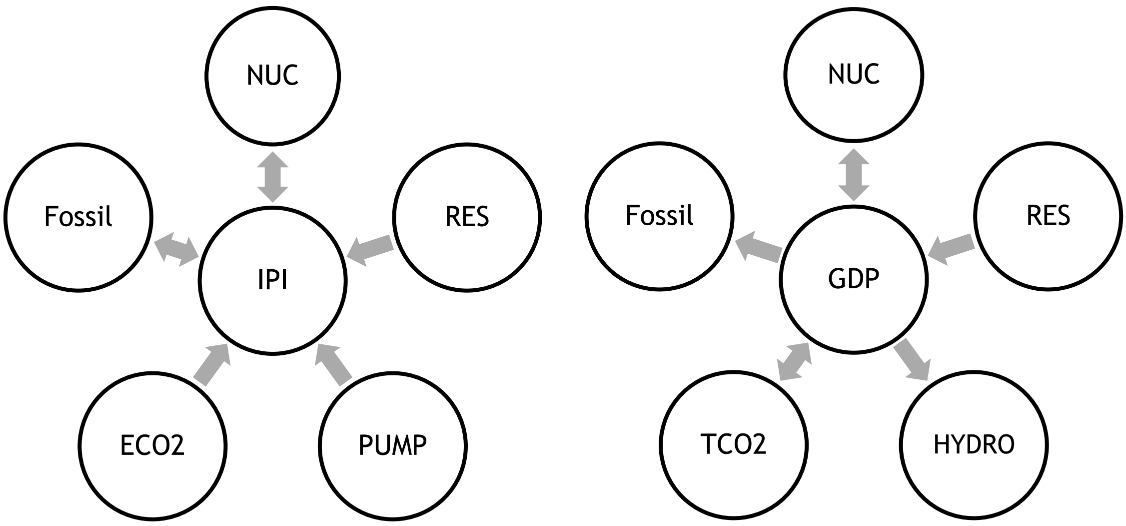

Fig. 5 - Relationship direction of electricity production sources, CO2, IPI (monthly data) and GDP (annually data)

The results for the *CO2* of the total economy (*TCO2*) based on the annual data frequency are in line with both the literature and the expectations. Indeed, it was found that: (i) fossil sources increase *TCO2* emissions; (ii) *NUC* decreases *TCO2*; and (iii) economic growth increases *TCO2*. In short, a bi-directional relationship is found between *GDP* and *TCO2* emissions.

Table 8 – ARDL Bounds Test

	$Model_A$- I_GDP	$Model_A$ - II_FOSSIL	$Model_A$ - III_HYDRO	$Model_A$ - IV_NUC	$Model_A$ - V_TCO2	$Model_A$ - VI_RES
F-Stat.	10.52575***	5.761345***	10.06349***	29.77954***	5.435560***	11.33061***
k	5	2	3	4	2	1
bottom	3.93	3.88	3.42	3.07	3.88	8.74
Top	5.23	5.3	4.84	4.44	5.30	9.63

Notes: k, represents the number of long-run variables without *ECM*; ***, represents 1% significance level.

The *ARDL* bounds test was also performed (Table 8) to verify the presence of cointegration. Such as in the monthly data framework, the presence of a long-run relationship under the annual frequency data is also proven. Based on the critical values provided by Pesaran et al. (2001), the null hypothesis of no-cointegration is rejected at a 1% significance level.

7. Discussion

The analysis of the dynamics of interaction between the electricity sources and their relationship with economic growth in France proves to be of particular interest, given that in this country, there is a dominant source of electricity: nuclear. This research takes particular interest in looking at how this dominant source interacts with both the new renewable sources and with other traditional, long-established sources, such as fossil fuels. A nuclear source reveals advantages comparable to the benefits from new sources of electricity. Such as noted, for instance by (Ben et al., 2015; Pedraza, 2015), the nuclear reduces energy dependence from abroad and has a lower marginal cost of electricity generation. The leading role of nuclear energy in economic growth in France has been proven in this investigation, and the feedback hypothesis is verified in both the short- and the long-run for this source. Besides the leading role in economic growth exerted by nuclear power, the achievements suggest that nuclear source is playing a baseload role in the French electricity system, which is strongly consistent with the proof of the feedback hypothesis for this source.

The special features of nuclear allow to accommodate the progressive integration of renewables into the system. In fact, in addition to the nuclear baseload role in the system, it seems that nuclear power is also supporting the intermittent availability of renewable resources, such as wind and solar PV, thereby permitting the deployment of these renewable electricity sources. In this way, nuclear power assumes a double role: baseload and backup, in the same way as coal and oil. Note that nowadays, with the development of techniques for forecasting resource availability on a timelier basis, it is feasible to backup with technologies other than those which can be quickly turn on/off. It is also worthwhile to note that the international trade of electricity in France was not revealed as statistically significant. This fact largely helps to explain why the French electricity system has remained relatively closed from the exterior, despite the pressure exerted by other EU members, such as the Iberian countries Portugal and Spain.

It is worthwhile to note, that incentive renewables may be producing an unintended effect. Indeed, in line with some literature (e.g. Marques and Fuinhas, (2012); Ocal and Aslan, (2013)), the investigation confirm that the wind power has constricting economic growth in France. This adverse effect could be a result of the lack of investment in other sources of production due to the resilient position held by nuclear source. On the contrary, solar PV source has contributing to enhance economic growth.

This study shows that the *CO2* emissions are not statistically significant in explaining the behaviour of nuclear power. Conversely, these emissions have been reduced with the use of nuclear source, as shown by the results based on the annual frequency framework, although only on the short-run. Moreover, in an indirect manner, nuclear power is also contributing to a more environmentally sustainable economy by allowing the deployment of renewables. Another interesting outcome is that the *CO2* emissions have led to greater use of *RES*, but the opposite is not confirmed, i.e. larger use of renewables is not cutting emissions of *CO2*. Although unexpected, this outcome is far from new in literature (e.g. Menyah and Wolde-Rufael, 2010).

Policymakers are faced with an enormous challenge. *CO2* emissions are pushing up *RES* and leading to a cleaner economy, but in the meantime, the change in sources that decrease *CO2* emissions may lead to a decrease in economic growth. A balance must be established and policymakers ought to design energy policies in which they do not have to choose between a cleaner economy and a fast growing one. It comes clear that the policies should be not technology neutral. Such as proved in this dissertation, the effects of each source on growth are dissimilar and this fact must be not omitted. This means that some of the outcomes regarding the renewables could come just because the policies tends to be designed for renewables, instead of for each individual source.

Regarding the interactions between sources, fossil fuels could be replaced by solar PV but not by wind power. Indeed, larger installed wind capacity in France has not diminished the need for using fossil fuels. As such, two contrary effects are observed here. On the one hand, the use of gas has allowed the substitution effect, i.e. more gas, less renewables, unlike coal and oil that grow simultaneously with renewables. This outcome is expected since gas is recognised as the transition source between paradigms. Indeed, gas is a more environmentally friendly source, with the advantage that it can be stored. One last note to highlight is that there is a significant positive trend towards the renewables model, confirming well-established ideas about the increasingly autonomous path of these sources, which is mainly a consequence of the decisions of political nature.

In short, this work uses data on a monthly basis as a reference framework, since the availability of such data enables control of the specific effect of each source. Even so, using a moderately time-length sample due to lack of data, the *ARDL* bounds test approach proves to be efficient, such as Ang (2007) described for small samples. This option of using the monthly frequency turned out to be appropriate, and the findings obtained for the shorter period are broadly corroborated in the longer period (annual frequency). The annual frequency allows the use of *GDP* to measure economic growth, as in the traditional literature. However, this work proves that the sectorial proxy *IPI* can be a reliable proxy for economic growth. Indeed, the following were proven: (i) the feedback hypothesis between the nuclear source and economic growth; (ii) the conservation hypothesis for the hydro source; and (iii) that *CO2* emissions have a positive relationship with the economic growth. These outcomes are achieved in both data frequency approaches, thus using *GDP* and *IPI* as variables of economic growth.

8. Conclusions

This dissertation is focused on the analysis of the dynamics of adjustment within the electricity mix and its relationships with economic growth in France. With this aim, the use of the *ARDL* and *ARDL* bounds test for the monthly frequency (January 2010 to November 2014) and annual frequency (1970 to 2012) reveals their suitability for studying the different types of electricity-growth nexus in France. The results coming from the two data frameworks (monthly and annual) are addressed and the consistency between them is confirmed. It is worthwhile to note that is debatable to refer to the long-run effects considering monthly data for a small number of years (4), despite all available data has been used. However, on the one hand, the number of monthly observations allow refer to a long memory, at least an *ECM* is present. On the other hand, the annual data frequency allows corroborate the findings on the long-run (43 years). Notwithstanding the moderate number of observations, the monthly frequency data reveals to be crucial to understand the relationships between the several electricity sources.

Nuclear power in France is a dominant source in the electricity mix, and this source is playing its expected role in the French economy. Indeed, there is evidence for the feedback hypothesis for the nuclear source, both on the short- and on the long-run. Nuclear source also contributes to a reduction in total *CO2* emissions, even in the short-run. These *CO2* emissions lead to a greater use of *RES*, but a higher use of *RES* does not affect the emissions of *CO2*. Accordingly, this work provides clear clues for designing appropriate energy policies. The policymakers in France should be aware that any reduction in nuclear source may lead to reduced economic growth. This could make the country miss their environmental targets, in similar way of Qvist and Brook, (2015) in the Sweden case. As such, it is strongly recommended a smooth path of the electricity sources transition, for example by keeping updated the nuclear technology.

The research also supported that the opening of the French electricity system could favour its economy. Indeed, the integration of other countries in the electricity network, such as the Iberian Peninsular system from Spain and Portugal, could promote a more efficient management of the system as a whole, for example by sharing backups to renewables. Regarding renewables sources dissimilar outcomes were observed. On the one hand, wind power constrains economic growth. On the other hand, solar *PV* stimulates economic growth, therefore greater penetration of solar *PV* source should be pursued. This kind of technology operates at a smaller scale, with lower capital investment and greater geographical dispersion. This can create a larger multiplying effect for the whole economy, with greater incorporation of labour in facilities and maintenance. Due to solar *PV* technology's characteristics, specifically, its small and medium scale operation and its creation of decentralized employment, policies focused on the deployment of this source should be enlarged, in particular by promoting the wider use of solar *PV* to generate electricity for self-consumption.

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Appendix

Table A.1 – Unit Root test (annual frequency)

	ADF			PP			KPSS	
	a)	b)	c)	a)	b)	c)	a)	b)
LTCO2	-1.9496	-1.0204	-0.7023	-2.1309	-1.0976	-0.6838	0.1206*	0.4797**
DLTCO2	-5.8786***	-5.9429***	-5.9274***	-5.8786***	-5.9376***	-5.9274***	0.0982	0.1016
LCOAL	-2.7181	-1.4810	-0.6033	-2.7181	-1.4810	-0.7112	0.0796	0.6184**
DLCOAL	-7.1053***	-7.1841***	-7.1915***	-7.1047***	-7.1667***	-7.1728***	0.0609	0.0752
LFOSSIL	-1.7167	-1.1994	-0.5899	-1.8862	-1.2373	-0.6057	0.1518**	0.5075**
DLFOSSIL	-6.5999***	-6.6826***	-6.6816***	-6.6025***	-6.6853***	-6.6739***	0.1079	0.1060
LGAS	-1.3511	-1.6685	0.4033	-1.1928	-0.7657	0.6377	0.1875**	0.3350
DLGAS	-3.9836**	-3.9293***	-3.9633***	-4.0244**	-3.9911***	-4.0060***	0.1114	0.2157
LGDP	-2.0294	-3.8895***	3.0807	-2.2016	-3.5993***	6.0826	0.1990**	0.8224***
DLGDP	-5.0541***	-4.3379***	-2.7677***	-4.9231***	-4.2357***	-2.6726***	0.0716	0.5638**
LHYDRO	-3.9433**	-4.0029***	0.0316	-3.9433**	-3.9243***	-0.0213	0.1541**	0.1538
DLHYDRO	-9.8629***	-9.8217***	-9.9552***	-23.112***	-12.1358***	-12.3284***	0.5000***	0.4280*
LNUC	-1.3398	-2.1557	1.1346	-1.4034	-3.7999***	2.3391	0.2074**	0.6846**
DLNUC	-2.2090	-1.7126	-1.7252*	-5.0509***	-4.2420***	-3.7539***	0.0642	0.6590**
LNX	-2.2656	-2.3559	-0.1606	-2.2656	-2.3812	-0.1610	0.1419*	0.1533
DLNX	-6.7800***	-6.8152***	-6.9020***	-6.8409***	-6.8365***	-6.9268***	0.0589	0.1255
LOIL	-1.9563	-0.6749	-1.2561	-2.2612	-0.7985	-1.2451	0.1297*	0.6561**
DLOIL	-6.1646***	-6.2531***	-6.0449***	-6.1633***	-6.2542***	-6.0694***	0.0830	0.0926
LRES	-0.9166	1.6991	2.2462	-0.4533	3.0063	3.4223	0.1805**	0.7815***
DLRES	-4.0687**	-3.2330**	-2.3267**	-3.7558**	-3.1983**	-2.1981**	0.0650	0.5970**

Notes: a) Trend and intercept; b) Intercept; c) None; *,**,***, represents 10%,5%,1% of significance respectively; ADF, stands for Augmented Dickey–Fuller test; PP: stands for Phillips–Perron test; KPSS: stands for Kwiatkowski–Phillips–Schmidt–Shin; D stands for the first differences;

Table A.2 – ARDL models and coefficients (annual frequency)

	$Model_A$-I_GDP	$Model_A$ - II_FOSSIL	$Model_A$ - III_HYDRO	$Model_A$ - IV_NUC	$Model_A$ - V_TCO2	$Model_A$ - VI_RES
DLRES	-	-	-	0.4512***	-	-
DLGAS	-	-	-0.2302**	-	-	-
DLNUC	-	-	-	-	-0.0463*	0.2164**
DLGDP	-	-	-	-	0.7719***	-
DLOIL	-	-	-	-	0.0877***	0.0812**
DLNX	-	-	-	-3.9468***	-	-
DLHYDRO	-	-0.3155**	-	-	-	-
DLTCO2	0.2474***	-	-	-	-	-
LFOSSIL(-1)	-	-0.3393***	-	-	-	-
LGDP(-1)	-0.5917***	0.4691***	0.5270***	0.1188*	0.0465***	-
LTCO2(-1)	0.2360***	-	1.2618***	-	-0.4108***	-
LNX(-1)	0.2364***	-	-	-2.3902***	-	1.7136***
LCOAL(-1)	-	-	-	0.3374***	-	-
LGAS(-1)	-0.0090**	-	-0.1549***	-	-	-
LOIL(-1)	-	-	-	-0.2063***	0.0507***	-
LNUC(-1)	0.0166**	-0.1841***	-	-0.1941***	-	-
LHYDRO(-1)	-	-	-0.7626***	-	-	-
LRES(-1)	-0.0438***	-	-		-	-0.0659***
C	15.4148***	-	-	-	-	-
TREND	0.0155***	-	-	-	-	0.0125***
ECM	-0.5917***	-0.3393***	-0.7626***	-0.1941***	-0.4108***	-0.0659***
Time Dummies						
ID2009	-0.0309***	-	-	-	-	-
ID1980	-	-	-	0.2330**	-	-
ID1997	-	-	-	-0.1654*	-	-
ID1990	-	-	-	-	-	0.3021***
Diagnostic Tests:						
ARCH	[0.3213](1) [0.5395](2) [0.3912](3)	[1.4660](1) [1.5870](2) [1.2867](3)	[1.9208](1) [0.9800](2) [1.0154](3)	[0.0013](1) [0.1347](2) [0.5240](3)	[0.2810](1) [0.3760](2) [0.2320](3)	[0.0840](1) [0.0794](2) [0.1938](3)
LM	[1.1020](1) [0.5944](2) [1.5934](3)	[0.5926](1) [0.5706](2) [0.4046](3)	[2.4649](3) [1.1982](2) [1.5954](1)	[0.3723](1) [0.7184](2) [1.1798](3)	[2.6648](1) [1.6655](2) [1.6594](3)	[0.9278](1) [0.6731](2) [0.8439](3)
JB	[0.0235]	[3.0762]	[0.1640]	[22.445***]	[1.3035]	[2.9290]
RESET	[0.0051]	[0.4122]	[1.5797]	[0.5553]	[1.1356]	[0.9423]

Notes: ***,**,*, represents 1%,5% and 10% of significance respectively; ARCH: test for heteroscedasticity (Bollerslev 1986); JB: Jarque–Bera normality test (Jarque and Bera, 1980); LM: Breusch–Godfrey serial correlation LM test (Breusch, 1978); RESET: Ramsey RESET(Ramsey, 1969); In (.) we encounter lag order; in [.] the F-statistic value

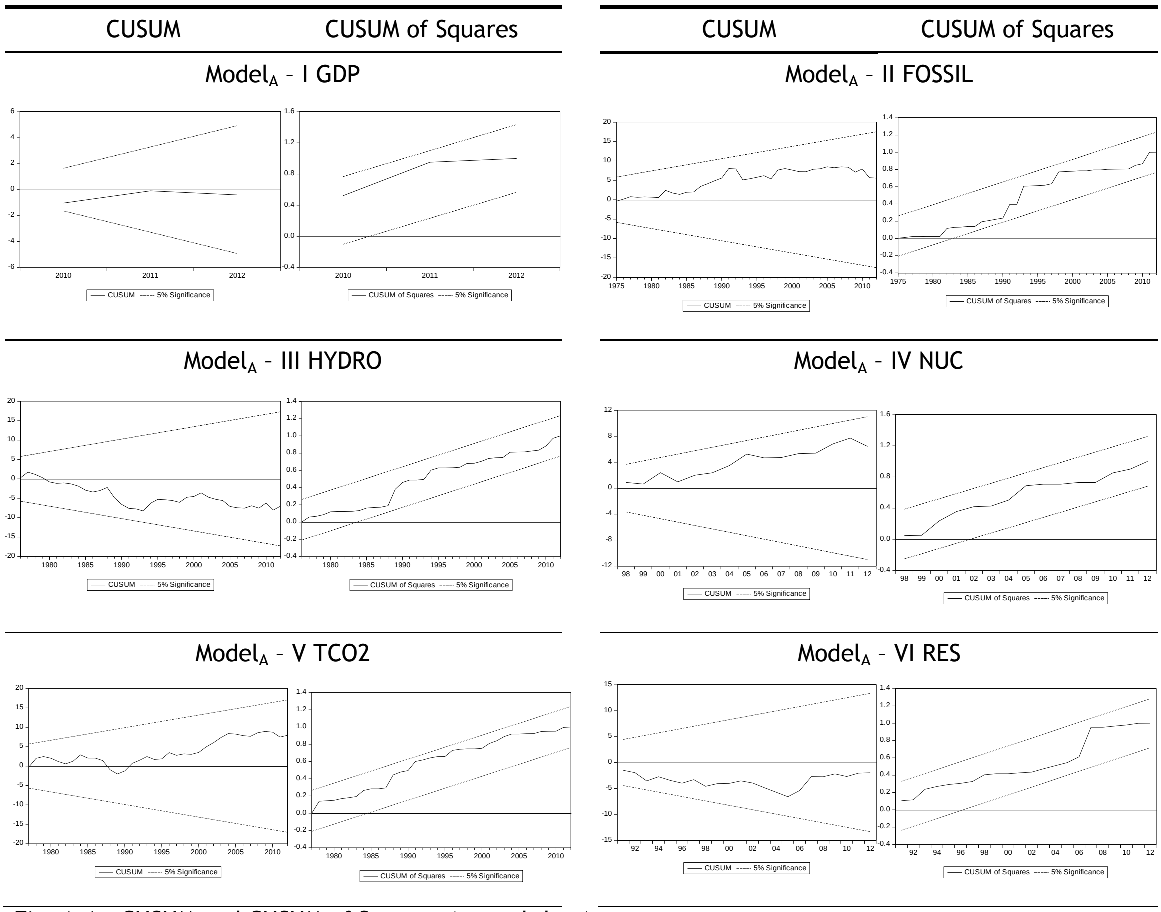

Fig. A.1 – CUSUM and CUSUM of Squares (annual data)