Empirical Study on the Environmental Kuznets Curve for CO2 in France: The Role of Nuclear Energy

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Empirical Study on the Environmental Kuznets Curve for CO_2 in France: The Role of Nuclear Energy*

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Abstract

This paper attempts to estimate the environmental Kuznets curve (EKC) in the case of France by taking the role of nuclear energy in electricity production into account. We adopt the autoregressive distributed lag (ARDL) approach to cointegration as the estimation method. Additionally, we examine the stability of the estimated models and investigate the Granger causality relationships between the variables in the system. The results from our estimation provide evidence supporting the EKC hypothesis and the estimated models are shown to be stable over the sample period. The uni-direction running from other variables to CO_2 emissions are confirmed from the casualty tests. Specifically, the uni-directional causality relationship running from nuclear energy to CO_2 emissions statistically provides evidence on the important role of nuclear energy in reducing CO_2 emissions.

Keywords: CO_2; Environment; EKC; Nuclear; France; ARDL

JEL classifications: Q43; Q51; Q53

1 Introduction

The Environmental Kuznets Curve (EKC) hypothesis claims that an inverted U-shaped relation exists between income and environmental pollu-

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tion or the usage of natural resources such as forest resources. While an increase in income causes environmental pollution and the degradation of natural resources at an earlier stage of economic growth, they are ameliorated at a later stage after a certain income level. Early empirical studies demonstrate the EKC between income and environmental pollutants such as sulfur dioxide (SO_2), nitrogen oxide (NOx), and suspended particulate matter (SPM).[1]

There is also vigorous discussion on whether the EKC for carbon dioxide (CO_2) emissions has been proved. CO_2 is considered to be the main source of global warming issues, attracting great attention in recent years. Countries have incentives to free-ride on the issue of reducing greenhouse gases because they spread beyond the borders to other countries. Since SO_2 and NOx lead to the direct impact on health and their polluted area is relatively limited, a country is less likely to be interested in reducing CO_2 emissions in its rapid economic development period in comparison to reducing SO_2 and NOx.

Our study focuses on the effect of nuclear power on the EKC for CO_2 emissions in France. The world demand for energy is increasing with economic growth and electricity can be produced by various resources such as oil, coal, natural gas, hydro, and nuclear power, the latter two of which exhaust little amounts of CO_2 emissions when producing electricity. Our study therefore analyses the EKC for CO_2 taking into account nuclear power generation.[2] It is interesting to analyze the case of France, which has the world highest nuclear power ratio to its entire amount of electricity produced (78%, 2003).[3]

Our estimation results show that the EKC for CO_2 emissions is proven in France and the effects of nuclear energy on CO_2 emissions are significantly negative. The causality tests confirm the uni-direction running from income and nuclear energy to CO_2 emissions. The estimated results show that the turning point in the relationship between income and CO_2 emissions is within the sample period. To check the robustness, our study estimates the model, adding trade or energy consumption in addition to income and nuclear energy. While the effects of trade or energy consumption are insignificant, the EKC for CO_2 is still satisfied and the effects of nuclear power are

[1]See Grossman and Krueger (1993, 1995), Selden and Song (1994), Suri and Chapman (1998), and Agras and Chapman (1999).

[2]Both hydropower and nuclear power generation exhaust less CO_2 emissions. Our paper, however, focuses on nuclear power generation because the hydropower ratio to the total electricity produced is low in most countries except for a few nations, such as Canada, which possess plenty of water resources.

[3]World Development Indicator's CD-ROM (2007) released by World Bank.

also significantly negative.

The previous literatures on the EKC related to our study are as follows. Shafik (1994) and Holtz-Eakin and Selden (1995) conclude that the amount of CO_2 emissions monotonically increases with per capita income. Soytas *et al.* (2007) find no causality relation from income to CO_2 emissions, including the energy consumption in the analysis on the EKC in the U.S. On the other hand, Liu (2005) studies the 24 OECD nations using the panel data. By analyzing the GDP and CO_2 emissions in a simultaneous equation system and considering each country's energy consumption as well as income, he concludes that the EKC for CO_2 exists. In Jalil and Mahmud (2009), the EKC is proven for China, taking into account the effects of trade. These researches have not produced clear evidence of the EKC for CO_2 emissions.

Richmond and Kaufman (2006), an earlier study considering nuclear power generation, investigate the EKC for CO_2 using the panel data of OECD countries and non-OECD countries. They point out that there is limited support of the EKC in the case of OECD countries, but not in the case of non-OECD countries. However, the time series analysis on the EKC for an individual country may be able to clarify the effects, which may be overlooked in the panel data analysis. Ang (2007) is one of the previous studies on the EKC for CO_2 in France. He argues that the EKC hypothesis is satisfied in France, by including energy use in the commercial field. Our study, on the other hand, is not just limited to energy use, but focuses on nuclear power generation, which addresses the production side of electrical energy. This paper therefore studies electricity use outside of the commercial field such as in the household, for instance.

The structure of this paper is as follows. Section 2 discusses the estimation methodology. Section 3 provides the empirical analysis, which includes data and the estimation results. Section 4 is the conclusion.

2 Estimation Methodology

According to the EKC hypothesis, there is a nonlinear quadratic relationship between income and environmental pollutants. However, since other variables than income can also exist as the determinants of CO_2 emissions, the omitted variable bias may occur if income is used as the only independent variable. In order to avoid this problem, it is necessary to add other variables, which could have influence on CO_2 emissions. This study will pay attention to the effects of nuclear energy, trade, and energy consumption in addition to income.

The fraction of nuclear power generated electricity to the total electricity produced in France was 78% in 2003, which was the largest in the world. In addition, CO_2 emissions are much smaller for electricity produced by nuclear and hydro power than that of coal, oil, or natural gas.

Given the above discussion, our baseline estimation model can be written as below in logarithm version.

$$\ln(co_2)_t = \alpha_0 + \alpha_1 \ln y_t + \alpha_2 (\ln y_t)^2 + \alpha_3 \ln nuc_t + \varepsilon_t, \tag{1}$$

where co_2 is per capita CO_2 emissions; y represents per capita real GDP; nuc stands for electricity production from the nuclear source (% of total) and ε is the standard error term.

Based on the EKC hypothesis α_1 is expected to be positive, whereas α_2 is expected to be negative. Since nuclear energy could be a factor leading to the reduction of CO_2 emissions, α_3 is expected to be negative.

For the estimation, we use the cointegration technique as our methodology. To conduct the cointegration analysis, there are several approaches such as the residual-based approach proposed by Engle and Granger (1987) and the maximum likelihood-based approach proposed by Johansen and Juselius (1990). When there are more than two I(1) variables in the system, the latter has the advantage over the former. These approaches, however, have disadvantages due to the requirement that the variables in the system must have the same order of integration. This requirement often causes difficulty to researchers when the system contains variables with different orders of integration. To overcome this problem, Pesaran *et al.* (2001) propose a new approach known as the autoregressive distributed lag (ARDL) for cointegration analysis which does not require the classification of variables into I(0) or I(1). Here, we adopt this new approach.

The estimation equation (1) above can be written as an unrestricted error correction representation of the ARDL model below.

$$\begin{aligned} \Delta \ln(co_2)_t = {} & \beta_0 + \sum_{i=1}^{n} \beta_{1i} \Delta \ln(co_2)_{t-i} + \sum_{i=1}^{n} \beta_{2i} \Delta \ln y_{t-i} + \sum_{i=1}^{n} \beta_{3i} \Delta \left(\ln y_{t-i}\right)^2 \\ & + \sum_{i=1}^{n} \beta_{4i} \Delta \ln nuc_{t-i} + \lambda_1 \ln(co_2)_{t-1} + \lambda_2 \ln y_{t-1} \\ & + \lambda_3 \left(\ln y_{t-1}\right)^2 + \lambda_4 \ln nuc_{t-1} + \mu_t, \end{aligned} \tag{2}$$

where μ_t is the standard error term.

The steps of the ARDL procedure are as follows. First, the existence of the long-run relation between the variables in the system is tested. The null hypothesis of no cointegration or no long-run relationship, $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$, is tested against its alternative, $H_1 : \lambda_1 \neq 0, \lambda_2 \neq 0, \lambda_3 \neq 0, \lambda_4 \neq 0$. The critical values of the F-statistics in this test are available in Pesaran and Pesaran (1997) and Pesaran *et al.* (2001). They provide the bands covering all the possible classifications of the variables into I(0) or I(1), or fractionally integrated ones. If the computed F-statistic is higher than the appropriate upper bound of the critical value, the null hypothesis of no cointegration is rejected; if it is below the appropriate lower bound, the null hypothesis cannot be rejected, and if it lies between the lower and upper bounds, the result is inconclusive. In the second step, the lag orders of the variables are chosen using the Akaike Information Criteria (AIC), and the short-run and long-run models are estimated following the selected ARDL models.

In this paper, the stability tests, namely, CUSUM (Cumulative Sum) and CUSUMSQ (CUSUM of Squares) of recursive residuals are also conducted.[4] Recently, many researchers incorporate these stability tests with the cointegration analysis due to the fact that even when the cointegration relationship is confirmed, it does not imply the stability of the estimated model.[5] Thus, the stability tests such as CUSUM and CUSUMSQ need to be conducted. Furthermore, we investigate the causal relationship between CO_2 emissions and other variables in the system as well because the information on the causality direction may be useful for policy implication.

Given the fact that other factors such as trade and energy consumption may also affect CO_2 emissions besides per capita income and nuclear energy, equation (1) will be expanded to incorporate these two factors respectively. Trade, here, is the sum of export and import as the percentage of GDP, which should be considered as a country's openness. Previous studies such as Ang (2007) and Jalil and Mahmud (2009) also take trade and energy consumption into account in their studies for the cases of the EKCs in France and China.

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[4]These tests are originally proposed by Brown *et al.* (1975).

[5]These stability tests are applied especially in the empirical studies on money demand functions. For example, Bahmani-Oskooee and Chomsisengphet (2002) estimate the money demand function in industrial countries and find that even though there is evidence of cointegration relationships in those selected countries, when incorporating the CUSUM and CUSUMQ stability tests into the cointegration procedure, some signs of instability are found in the cases of Switzerland and UK. The previous studies on the determinant of CO_2 emissions such as Ang (2009) and Jalil and Mahmud (2009) incorporate the CUSUM and CUSUMSQ stability tests with the cointegration analysis.

3 Empirical Analysis

3.1 Data

Our study uses the annual data spanning from 1960 to 2003 for estimation. This sample is chosen based on the availability of all data. CO_2 emissions (co_2) are measured as metric tons per capita. Real GDP (y) is GDP per capita in constant local currency. Electricity produced from the nuclear source (nuc) is the percentage of the total electricity produced. Trade (tr) is the total trade as the percentage of GDP. Per capita energy use or consumption (en) is measured as kg of oil equivalent per capita.

All data is obtained from the World Development Indicator's CD-ROM (2007) released by World Bank.

3.2 Estimation Results

Our analysis starts with the F-test to confirm the existence of the long-run or the cointegration relationship between the variables in equation (2). As stated in Bahmani-Oskooee and Nasir (2004), F-test results for long-run relationships are sensitive to the number of lags set for each first-different variable in the equation. Therefore, we select the optimal lag order by using the AIC. Setting the maximum lag lengths up to 3, the results indicate that 1 is the optimal lag order.[6] F-test results of the baseline equation (2) based on the selected optimal lag order are reported in Table 1 as case 1. The F-statistic indicates that there is evidence of the long-run or cointegration relationship between the variables because it is above upper bounds of the

Table 1: F-statistics of Bound Tests

Lag order	1	Result
Case 1	4.499**	Cointegration
Case 2	3.353	Inconclusive
Case 3	3.630*	Cointegration

Note: 1. ***, ** and * are respectively the 1%, 5% and 10% of the significant level.

2. Case 1 is the baseline equation case. Cases 2 and 3 are the cases in which trade and energy consumption are included in the baseline equation respectively.

3. 10% CV [2.425, 3.574], 5% CV [2.850, 4.049], 1% CV [3.817, 5.122] for case 1.

4. 10% CV [2.262, 3.367], 5% CV [2.649, 3.805], 1% CV [3.516, 4.781] for cases 2 and 3.

[6] Given the number of variables in the equations, our sample size is quite small. Therefore, we set the lag order up to 3 lags to ensure sufficient degrees of freedom for econometric analysis.

critical values.The results of cases 2 and 3 reported in Table 1 are the results of the cases in which the baseline equation (1) is expanded to incorporate trade and energy consumption respectively. When incorporating trade or energy consumption in the baseline equation (1), the null and alternative hypotheses for conducting F-tests include the coefficient of trade or energy consumption as well. We also conduct optimal lag selection for these cases by setting the maximum lag lengths up to 3. Based on the AIC, the optimal lag order for cases 2 and 3 is 1. With this optimal lag order, case 3's F-test result also supports the evidence of a long-run or cointegration relationship among variables similar to case 1.

However, for the result of case 2, the F-statistic lies between the lower and upper bounds of critical values, indicating that it is inconclusive whether or not the null hypothesis of no cointegration relationship should be rejected. Therefore, we should conduct the unit root tests. Based on the Phillips-Perron tests, the results show that if only intercepts are included in the test equations, $\ln y$, $(\ln y)^2$, $\ln nuc$ and $\ln en$, are I(0), whereas $\ln co_2$ and $\ln tr$ are I(1). However, when both intercepts and time trends are included in the test equations, all series are shown to be I(1).[7] These results provide the possibility of the existence of a long-run or cointegration relationship among variables.

Next, we estimate baseline equation (2) and the expanded equations using the ARDL approach. The optimal lag length is set to 1 according to the lag selection result above. Given this, the AIC-based ARDL suggests ARDL(1,0,0,0) for the baseline case (case 1), ARDL(1,0,0,0,0) for the trade included case (case 2) and ARDL(1,0,0,0,1) for the energy consumption included case (case 3).[8] Short-run estimation results in the error correction representations of all 3 cases are provided in Table 2. This indicates that the error correction terms (EC_{t-1}) of the cases 1, 2 and 3 are significant and have the correct sign. These provide the evidence of cointegration relationships among the variables. The absolute values of the coefficients of EC_{t-1} in all cases are quite high, indicating the fairly high speed of adjustment to the long-run equilibrium following short-run shocks.[9]

Table 3 presents the diagnostic tests: serial correlation, functional form,

[7]Unit root test results can be provided upon request. The mixed results of the unit root tests also give us the incentive to use the ARDL approach instead of conventional approaches of cointegration.

[8]ARDL(p, q, r, s) represents the ARDL model in which the first difference of the variables take the lag length p, q, r and s respectively.

[9]Ang (2007) finds the very high speed of adjustment for the case of France (-0.77), but his model does not include nuclear energy. Our estimated speed of adjustment is much lower than that of Ang (2007).

Table 2: The Error Correction Representation for the Selected ARDL Model

Variable	Case 1	Case 2	Case 3
	ARDL(1,0,0,0)	ARDL(1,0,0,0,0)	ARDL(1,0,0,0,1)
$\Delta \ln y_t$	16.170 (4.358)***	16.983 (4.901)***	7.225 (3.723)*
$\Delta(\ln y_t)^2$	-0.812 (0.220)***	-0.854 (0.250)***	-0.361 (0.186)*
$\Delta \ln nuc_t$	-0.116 (0.027)***	-0.120 (0.029)***	-0.072 (0.021)***
$\Delta \ln tr_t$	-	0.040 (0.107)	-
$\Delta \ln en_t$	-	-	0.955 (0.169)***
$\Delta Constant$	-79.191 (21.258)***	-83.125 (23.866)***	-36.334 (22.281)**
EC_{t-1}	-0.434 (0.104)***	-0.462 (0.128)***	-0.233 (0.086)***
$\bar{R}^2$	0.380	0.366	0.672
DW-statistics	2.232	2.193	2.469
SE of Regression	0.043	0.044	0.031

Case 1: $EC = \ln co_2 - 37.21 \ln y + 1.86\,(\ln y)^2 + 0.26 \ln nuc + 182.26C$

Case 2: $EC = \ln co_2 - 36.73 \ln y + 1.84\,(\ln y)^2 + 0.26 \ln nuc - 0.08 \ln tr + 179.80C$

Case 3: $EC = \ln co_2 - 30.98 \ln y + 1.54\,(\ln y)^2 + 0.31 \ln nuc - 0.49 \ln en + 155.84C$

Note: 1. ***, ** and * are respectively the 1%, 5% and 10% of the significant level.

2. Case 1 is the baseline equation case. Cases 2 and 3 are the cases in which trade and energy consumption are included in the baseline equation respectively.

3. The numbers in parentheses are standard errors.

normality, and heteroscedasticity tests. From the results, we can see that only case 1 (baseline equation) can pass all tests, while case 2 can pass three and case 3 can pass two out of four tests.

Table 4 provides the long-run estimation results.[10] Except for the coefficients of $\ln tr$ in case 2 and $\ln en$ in case 3, all estimated coefficients are statistically significant and have correct signs as expected, supporting the evidence of a long-run relationship among the variables. The significant coefficients of $\ln y$ and $(\ln y)^2$ with the expected signs provide the evidenceof an inverted U-shaped relationship between income and environment pollution, supporting the EKC hypothesis. This finding is consistent with Ang (2007), whose estimation model does not incorporate nuclear energy. The estimated long-run elasticity of CO_2 on nuclear energy is around -0.27 to -0.31, indicating that a 1% increase in electricity produced from nuclear sources leads to about a 0.27 to 0.31% decrease of per capita CO_2 emissions.

As for the long-run elasticity of CO_2 emissions with respect to income y, the estimated results are $37.215 - 3.737 \ln y$ for case 1, $36.736 - 3.698 \ln y$

[10] We also estimate the model in which only income and its square are included as the independent variables. The long-run result, however, indicates that all estimated coefficients are not statistically significant.

Table 3: Diagnostic Tests

Diagnostic Test:	Serial Correlation	Functional Form	Normality	Heteroscedasticity
	$\chi^2(1)$ [p-value]	$\chi^2(1)$ [p-value]	$\chi^2(1)$ [p-value]	$\chi^2(1)$ [p-value]
Case 1	0.906	0.011	2.333	2.340
	[0.341]	[0.916]	[0.311]	[0.126]
Case 2	0.688	0.030	2.056	2.979
	[0.407]	[0.860]	[0.358]	[0.084]
Case 3	2.909	1.378	34.912	3.027
	[0.088]	[0.240]	[0.000]	[0.082]

Note: Case 1 is the baseline equation case. Cases 2 and 3 are the cases in which trade and energy consumption are included in the baseline equation respectively.

for case 2 and $30.988 - 3.099 \ln y$ for case 3, respectively. Based on these results, the logarithm income level turning points of the EKC are calculated. The results are reported in Table 4 as $\ln y^{MAX}$. In all cases, although the calculated values of $\ln y^{MAX}$ are higher than the actual turning point value of $\ln y$, which is around 9.5-9.6, they are lower than the highest actual value over the sample period. This finding is natural given the fact that France is a developed country whose growth status is mature.[11] Our finding is consistent with that of Ang (2007).

Table 4: Long-Run Estimation Results

Variable	Case 1	Case 2	Case 3
$\ln y_t$	37.215 (4.545)***	36.736 (4.482)***	30.988 (10.903)***
$(\ln y_t)^2$	-1.868 (0.227)***	-1.849 (0.221)***	-1.549 (0.527)***
$\ln nuc_t$	-0.267 (0.052)***	-0.260 (0.052)***	-0.312 (0.094)***
$\ln tr_t$	-	0.088 (0.219)	-
$\ln en_t$	-	-	0.490 (0.653)
Constant	-182.261 (22.658)***	-179.808 (22.375)***	-155.843 (51.679)***
$\ln y^{MAX}$	9.956	9.932	9.997

Note: 1. ***, ** and * are respectively the 1%, 5% and 10% of the significant level.
2. The numbers in parentheses are standard errors.
3. Case 1 is the baseline equation case. Cases 2 and 3 are the cases in which trade and energy consumption are included in the baseline equation respectively.

[11] In the case of a developing country, the EKC's turning point may or may not be within the observed sample period. For example, Jalil and Mahmud (2009) find that the EKC's turning point of China lies outside of the observed sample period.

It is worth noting that when incorporating nuclear energy in electricity production as well as energy consumption into the estimation model unlike Ang (2007), the coefficient of energy consumption is not statistically significant in the long-run although it is significant in the short-run. One possible interpretation is that while energy consumption increases CO_2 emissions, nuclear energy exhausts less CO_2 emissions. The effect of the latter on CO_2 emissions seems to be greater. For the impact of trade, although the coefficient sign is positive, it is not statistically significant. This finding is consistent with that of Jalil and Mahmud (2009) in the case of China.

To test the stability of the estimated models, CUSUM and CUSUMSQ tests are employed. Figures 1, 2 and 3 present the plots of the tests. The plots of both CUSUM and CUSUMSQ tests are within the criteria bands, indicating that our estimated models are stable.

Figure 1: Plot of CUSUM and CUSUMSQ of Case 1

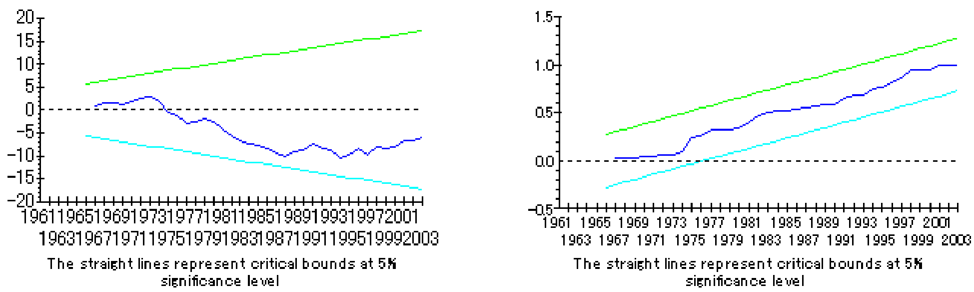


Figure 2: Plot of CUSUM and CUSUMSQ of Case 2

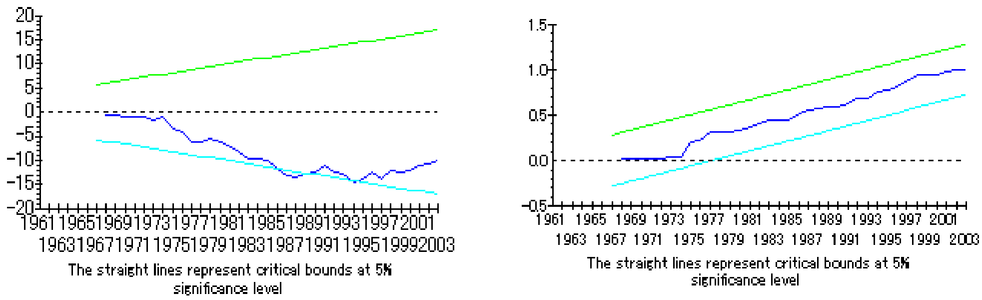
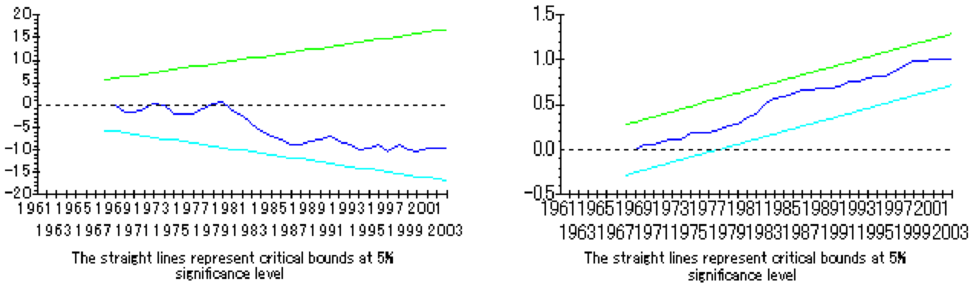


Figure 3: Plot of CUSUM and CUSUMSQ of Case 3



From the above results, it is evident that a stable cointegration relationship exists among the variables in all equations. This also implies the existence of the causal relation between those variables. However, in order to identify the direction of the relationships, the causality test needs to be conducted. We apply the pair wise Granger causality test. The F-statistics and p-values in Table 5 provide the evidence of the uni-directional link running from income (GDP), nuclear energy, trade, and energy consumption to CO_2 emissions. These results imply that while economic growth causes more CO_2 emissions, any effort to reduce CO_2 emissions does not restrain the development of the economy. Our result on the uni-directional causality relationship from nuclear energy to CO_2 emissions provides the evidence of its contribution in cutting CO_2 emissions.

Table 5: Pair Wise Granger Causality Tests

Null Hypothesis (H_0)	F-Statistic	P-value	Result
$\ln co_2$ does not Granger cause $\ln y$	0.907	0.346	Accept H_0
$\ln y$ does not Granger cause $\ln co_2$	6.697	0.013	Reject H_0
$\ln co_2$ does not Granger cause $(\ln y)^2$	0.822	0.369	Accept H_0
$(\ln y)^2$ does not Granger cause $\ln co_2$	6.721	0.013	Reject H_0
$\ln co_2$ does not Granger cause $\ln nuc$	0.929	0.340	Accept H_0
$\ln nuc$ does not Granger cause $\ln co_2$	7.513	0.009	Reject H_0

4 Conclusion

In this paper, unlike previous studies, we estimate the environmental Kuznets curve for the case of France by taking nuclear energy in electricity production into account. Due to the fact that other factors such as international trade and energy consumption may also have impacts on CO_2 emissions, we expand our estimation model by including these factors into the model. For the econometric technique, we adopt the autoregressive distributed lag (ARDL) approach to cointegration developed by Pesaran *et al.* (2001). Additionally, stability and causality tests are also conducted.

From the estimation results, we find evidence supporting the EKC hypothesis for the case of France. The stability tests also indicate that estimated models are stable over the sample period. The impact of nuclear energy on CO_2 emissions is shown to be significantly negative in both the short-run and long-run. For the impact of trade, our results point out that it is not statistically significant in both the long-run and short-run. On the impact of energy consumption on CO_2 emissions, unlike previous studies in the case of France, we only find evidence of statistical significance in the short-run, but not in the long-run.

Our finding on the uni-directional causality relationship running from income to CO_2 emissions implies that although economic growth causes more CO_2 emissions, any effort to reduce them does not restrain the development of the economy. This result is consistent with that of previous studies. In addition, from the result of the statistical significance on nuclear energy and uni-directional causality relationship running from nuclear energy to CO_2 emissions, our study statistically provides evidence of the important role of nuclear energy in reducing CO_2 emissions.

However, it is necessary to bear in mind that nuclear power generation requires safety management costs in order to avoid any accident that may potentially damage the environment and human beings.

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