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# $CO_2$ Emissions and Economic Growth in the West African Economic and Monetary Union (WAEMU) Countries

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**Abstract**

The objective of this work is to address the validity of a quadratic environmental Kuznets curve (EKC) hypothesis in the *West African Economic and Monetary Union (*WAEMU*) countries* over the period 1970-2010. The bound test procedure is used to analyze the relationship between $CO_2$ emissions and GDP. The results indicate that there is no long term relationship between these variables for the panel of 8 countries of the WAEMU. Similarly, the co-integration exists only in Benin, Mali and Togo. For the purposes of robustness check, additional variables (energy consumption and trade openness) and the Sasabuchi–Lind–Mehlum U test are used. The results confirm the validity of a quadratic carbon Kuznets curve only in Mali. Moreover, the validity of the "pollution havens" hypothesis suggests that the government of Mali should strengthen its environmental regulation policy to limit the influx of polluting industries in the country.

**Keywords:** $CO_2$ emissions, EKC hypothesis, Bound test, WAEMU

## 1. Introduction

The relationship between economic growth and environmental quality is relevant in a context strongly marked by technological progress and climate change. Most of the consequences of the degradation of environmental conditions are supported by developing countries. Indeed, environmental degradation caused by emissions of greenhouse gases may reverse the economic progress and developing countries will support between 75 and 80 % of the damage costs (Hope, 2009).

Any effective environmental policy should be able to address the determinants of environmental degradation. In economic theory, economic growth is considered as a source of pollution (Meadows et al, 1972). Thus, there is ample evidence about an inverted U-shaped relationship between income and environmental quality, which is inspired by Kuznets (1955) who found a similar relationship between income inequality and economic growth. Kuznets (1955) hypothesized that income inequality first rises and then falls as income per capita increases. The relationship between growth and environmental quality has been described in the literature of environmental Kuznets curve (EKC) (Panayotou, 1993). The EKC theory states that the early stages of economic growth are associated with the degradation of the quality of the environment. This trend should be reversed when economic growth reaches a high level (turning point).

Since the Kyoto Protocol in 1992, global partnerships and individual initiatives in each country are encouraged to reduce emissions of greenhouse gases. Yet in recent years, the West African Economic and Monetary Union (WAEMU) countries have experienced an increase in their $CO_2$ emissions (*see Figure 1*). These emissions are positively correlated to the GDP. In the WAEMU countries like other countries, there is no *a priori* on the factors that explain the relationship between GDP and pollution.

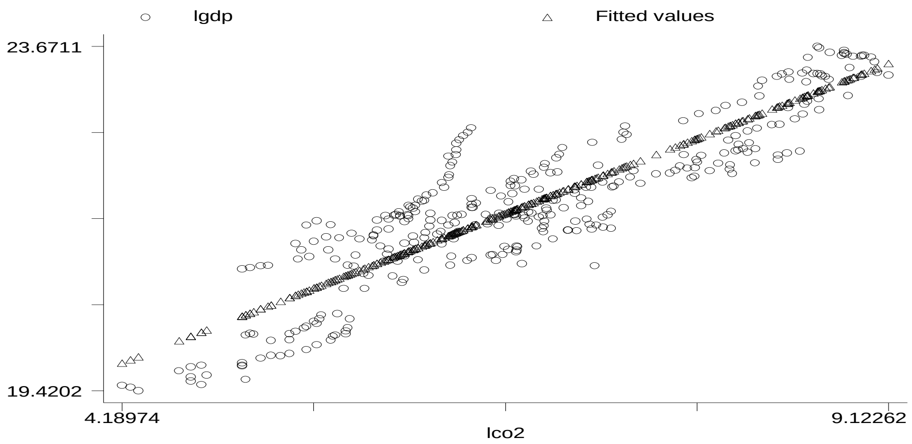


Figure 1. Income and $CO_2$ emissions in WAEMU

Source: Author, using data from the World Development Indicators (WDI 2015).

Beyond the income, several factors are often considered in the literature (Dinda, 2004). They include mainly energy consumption (Govindaraju and Tang, 2013; Ozcan, 2013; Shahbaz et al 2013; Yavuz, 2014), trade liberalization, foreign direct investment, growth of the population (Ahmed and Long, 2012; Onafowora and Owoye, 2014), urbanization (Hossain, 2011; Farhani and Ozturk, 2015), financial development (Ozturk and Acaravci, 2013), capital and labor (Menyah and Wolde-Rufael, 2010; Al-Mulali et al, 2015). These empirical studies found mixed results regarding the validity of the environmental Kuznets curve (EKC) hypothesis both in developed and developing countries.

As signatories to the Kyoto Protocol, the WAEMU countries have individual and collective responsibility to reduce their emissions of greenhouse gases. Therefore, one fundamental question emerges: Can the WAEMU countries reduce their pollution through economic progress? In other words, does environmental Kuznets curve (EKC) hypothesis valid in the WAEMU countries?

The contribution of this study is twofold. The first contribution is that the study provides empirical evidence of the EKC hypothesis in West African countries. Indeed, except few studies that focused on African countries (Orubu and Omotor, 2011; Osabuohien et al 2014; Lin and al, 2016), there is no empirical evidence of the EKC specifically on West African countries. As a second contribution, the study tests the sufficient condition of quadratic relationship between GDP and pollution. Until now, this condition has been tested only by Begum et al (2015) in the case of Malaysia.

The aim of this study is to check the validity of the EKC hypothesis in the WAEMU countries during the period 1970-2010. The existence of a long-term relationship between the variables is tested for all the eight WAEMU countries with a panel (pooling data) on the one hand and for each country (time series) on the other hand. The results indicate that there is no panel co-integration between GDP and $CO_2$ emissions. A more suitable approach to the analysis of the relationship between economic growth and pollution would be the examination of historical experience of individual countries (Stern et al., 1996), as there is a difference in state level per capita emissions. Using country-specific data, the results show that there is a relationship between income and pollution in Benin, Mali and Togo. Therefore, the results reported and analyses focused on these three countries of the WAEMU.

The remainder of the article is structured in five sections. The first section presents the theoretical and empirical review of the environmental Kuznets curve literature, the second describes the methodology and data, the third section presents the main results, the fourth section focuses on the discussion of the results, and the last section concludes the paper while providing policy implications of the results.

## 2. Theoretical and Empirical Analyses of the Relationship between Pollution and Economic Growth

The relationship between pollution and economic growth has been discussed in the literature since the work of Kuznets (1955). Theoretically, in the early stages of development, economic growth leads to degradation of the environment and after a certain level of growth (turning point), it follows an improvement in environmental conditions. That is known as environmental Kuznets curve hypothesis. Several factors such as (i) the scale effect, (ii) the technological effect and (iii) the "pollution havens" hypothesis or technology transfer could explain this relationship between growth and the environment (Grossman and Krueger, 1995).

The scale effect that tends to prevail in the early stages of economic growth is based on the idea that production growth is accompanied by an increase in inputs required for industrial production. More generally, rapid industrialization, population growth and changes in life style are the major factors of increased energy consumption (Apergis and Ozturk, 2015). With increasing energy consumption, the level of carbon emissions is expected to rise and this will contribute further to global warming. However, higher energy consumption in goods production is supposed to allow economic growth that is associated with technological progress. Thus, economic growth is a source of technological progress that causes a replacement of obsolete techniques by "environmentally friendly" techniques (*technological effects*). The technological effect shows that the environmental impacts of economic growth may depend on changes in production techniques. The impact of economic growth on the quality of environment could be positive or negative depending on the changes in the structure of production of a country (composition effect). If a country produces less pollution-intensive goods as income growth, the composition effect will cause the environmental impacts of economic growth to decline (Brock and Taylor, 2005). As a whole, it appears that the scale effect has a positive effect on pollution while the technological effect affects pollution negatively. According to the pollution haven hypothesis (PHH), it refers to the possibility that multinational firms, particularly those engaged in highly polluting activities, relocate to countries with lower environmental standards (Dinda, 2004). Thus, the PHH or technology transfer effect depends to the degree of trade openness. On the one hand, trade openness fosters technology transfer through foreign direct investments that reduce pollution by the diffusion of clean technologies (Martin and Wheeler, 1992; Reppelin-Hill, 1999). On the other hand, openness may cause increased pollution for developing countries that will host polluting industries (pollution havens) due to their less restrictive regulations on environment. Although other factors explain the EKC hypothesis (Dinda, 2004), those mentioned above are the ones that widely received empirical support.

Empirical evidence of the EKC hypothesis was first established by Grossman and Krueger (1995) who found a non-linear relationship between pollution and income. The simplest empirical model relates the level of pollution ($CO_2$ emissions) to income level (GDP and $GDP^2$). Despite the different approaches, most of the studies confirmed the existence of the EKC (Fodha and Zaghdoud, 2010; Acaravci and Ozturk, 2010; Esteve and Tamarit, 2012; Hamit-Haggar, 2012; Saboori et al, 2012; Chow, 2014).

The basic model to test the validity of the EKC hypothesis was expanded further to take into account several control variables. Thus, energy consumption variable is mostly used to account for the scale effect (Ang, 2007; Apergis and Payne, 2009; Lean and Smyth, 2010; Wang et al, 2011; Shahbaz al, 2012; Chandran and Tang, 2013; Yavuz, 2014). The results have been mixed with respect to the evidence of the EKC. For example, the EKC is not confirmed in the case of Malaysia (Saboori and Sulaiman, 2013, 2013a) and China (Wang et al, 2011; Govindaraju and Tang, 2013) while it remains valid for other cases (Ang, 2007; Shahbaz et al, 2012). Similarly, with the bound test and Granger causality approaches, Saboori and Sulaiman (2013, 2013a) found in the case of Malaysia that the hypothesis is not valid when adding the variable "energy consumption" into the quadratic model but remains valid with foreign direct investment (Lau et al. 2014).

Foreign direct investment or trade openness variables are used in some studies as control variables to take into account the "pollution havens" hypothesis or technology transfer effect. All the studies using these variables confirmed the EKC hypothesis (see Table 1).

Finally, urbanization (Hossain, 2011; Sharma, 2011; Farhani et al, 2014; Farhani and Ozturk,

2015) and the population dynamics (Ahmed and Long, 2012; and Onafowora Owoye, 2014) are also considered as factors that increase the level of pollution. Begum et al (2015) found in the case of Malaysia that the growth of the population has no effect on $CO_2$ emissions while the study of Al-Muali et al (2015) showed that urbanization increases pollution in the long term in Europe.

The quadratic function has been challenged recently (Müller-Fürstenberger and Wagner, 2007). Using GDP and GDP square in one regression may cause an econometric problem due to the multicollinearity (Al-Mulali et al, 2015). Recent studies tested the EKC hypothesis through a linear function models taking into account the main determinants mentioned above (Al-Mulali et al., 2015; Bastola and Sapkota, 2015). In particular, in the case of Vietnam, the EKC hypothesis is invalidated because of the nonexistence of the pollution havens hypothesis (the capital increased pollution) and the positive effect of the GDP on $CO_2$ emissions in the short and long terms (Al-Mulali et al, 2015). The arguments against the quadratic function in investigating the EKC seem to be insufficient. Indeed, there are many recent studies that used the quadratic function to check the relationship between income and pollution (Begum et al., 2015; Ben Jebli and Ben Youssef, 2015; Lin et al, 2016). However, all these studies used quadratic function that integrates other variables besides GDP and GDP square. Using a quadratic function, Lin et al (2016) found that there is no evidence for an inverted U-shaped relationship between $CO_2$ emissions and economic growth in five African countries (Nigeria, Kenya, Congo, Egypt, South Africa), regardless of whether economic development is driven by agriculture or industrialization.

Table 1. Empirical studies on EKC hypothesis

| **Author (s)** | **Countries/regions** | **Methodology** | **Kuznets hypothesis** |
|---|---|---|---|
| **Variables: $CO_2$ emission, GDP, GDP square** | | | |
| Fodha and Zaghdoud (2010) | Tunisia | Johansen cointegration test, VECM Granger causality. | Yes |
| Acaravci and Ozturk (2010) | Europe | Bound test, VECM Granger causality | EKC relationship in only Italia and Denmark |
| Esteve and Tamarit (2012) | Spain | Threshold VECM model | Yes |
| Hamit-Haggar (2012) | Canada | Pedroni cointegration, fully modified OLS (FMOLS), VECM Granger causality | Yes |
| Saboori et al. (2012) | Malaysia | Bound test, VECM Granger causality | Yes |
| Chow (2014) | 132 developed and developing countries | OLS | Yes |
| **Variables: $CO_2$ emission, energy consumption, GDP, GDP square** | | | |
| Ang (2007) | France | Bound test, Johansen cointegration test, Granger causality | Yes |
| Apergis and Payne (2009) | Central America | Pedroni cointegration, fully | Yes |

| | | | |
|---|---|---|---|
| | | modified OLS (FMOLS), VECM Granger causality. | |
| Lean and Smyth (2010) | ASEAN | Fisher cointegration, dynamic OLS, VECM Granger causality. | Yes |
| Apergis and Payne (2010) | Commonwealth of Independent states | Pedroni cointegration, dynamic OLS, VECM Granger causality | Yes |
| Pao and Tsai (2010) | BRIC countries | Kao, Fisher, Pedroni cointegration tests, OLS, VECM Granger causality | Yes |
| Pao and Tsai (2011a,b) | Brazil | Gray prediction model, VECM Granger causality | Yes |
| Wang et al. (2011) | China | Pedroni cointegration, VECM Granger causality | No |
| Pao et al. (2011) | Russia | Johansen cointegration, OLS, Granger causality | No |
| Shahbaz et al. (2012) | Pakistan | Bound test , VECM Granger causality | Yes |
| Chandran and Tang (2013) | ASEAN | Johansen cointegration , VECM Granger causality | No |
| Saboori and Sulaiman (2013, 2013a) | ASEAN | Bound test, Granger causality | EKC relationship in only Singapore and Thailand |
| Saboori and Sulaiman (2013, 2013a) | Malaysia | Bound test, Granger causality | No |
| Govindaraju and Tang (2013) | China et India | Johansen cointegration | No |
| Ozcan (2013) | Middle East | Pedroni cointegration, fully modified OLS (FMOLS), VECM Granger causality | No |
| Shahbaz et al. (2013) | Romania | Bound test, Fixed effects and random effects model. | Yes |
| Yavuz (2014) | Turkey | Johansen cointegration, Gregory-Hansen cointegration, OLS | Yes |
| **Variables: $CO_2$ emission, energy consumption, GDP, GDP square, trade openness** | | | |
| Jalil and Mahmud (2009) | China | Bound test, Granger causality | Yes |
| Halicioglu (2009) | Turkey | Bound test, VECM Granger causality | Yes |
| Atici (2009) | Central and Eastern Europe | Fixed effects and random effects model. | Yes |
| Nasir and Rehman (2011) | Pakistan | Johansen co-integration, VECM Granger causality | Yes |
| Jayanthakumaran et al. (2012) | China and India | Bound test | Yes |
| Tiwari et al. (2013) | India | Bound test, VECM Granger | Yes |

| | | | |
|---|---|---|---|
| | | causality | |
| Shahbaz et al. (2014) | Tunisia | Bound test, VECM Granger causality | Yes |
| Farhani et al. (2014) | Tunisia | Bound test, VECM Granger causality | Yes |
| **Variables: $CO_2$ emission, energy consumption, GDP, GDP square, foreign direct investment** | | | |
| Haisheng et al. (2005) | China | Fixed effects and random effects model. | Yes |
| Pao and Tsai (2011a,b) | BRIC countries | Kao, Fisher, Pedroni cointegration tests, OLS | |
| Lau et al. (2014) | Malaysia | Bound test, Granger Causality | Yes |
| **Variables: $CO_2$ emission, energy consumption, GDP, GDP square, trade openness, population growth** | | | |
| Ahmed and Long (2012) | Pakistan | Bound test | Yes |
| Onafowora and Owoye (2014) | Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, South Africa. | Bound test, variance decomposition | EKC relationship in only Japan and South Korea |

| **Author(s)** | **Countries** | **Variables** | **Methodology** | **Findings** |
|---|---|---|---|---|
| Menyah and Wolde-Rufael (2010) | South Africa | Real GDP, energy consumption, $CO_2$, Gross fixed capital formation, employment | Bound test, Granger causality | Cointegration relationship between variables |
| Ozturk and Acaravci (2013) | Turkey | Financial development, trade, economic growth, energy consumption, carbon emission | Bound test | EKC relationship |
| Ben Jebli and Ben Youssef (2015) | Tunisia | $CO_2$ emission, energy consumption, GDP, nonrenewable energy consumption, trade. | Bound test, VECM Granger causality | No EKC relationship |
| Al-Mulali et *al* (2015) | Vietnam | $CO_2$ emission, GDP per capita, energy consumption (electricity), capital, labor, export, import | Bound test | No EKC relationship |
| Bastola and Sapkota (2015) | Nepal | GDP per capita, $CO_2$ emission per capita, energy consumption | Bound test, Granger causality | Economic growth contributed to CO2 emissions and energy consumption |

Source: Author

## 3. Methodology and Data

Several empirical analyses on the validity of the environmental Kuznets curve have examined the quadratic relationship between GDP and pollution (Fodha and Zaghdoud, 2010; Acaravci and Ozturk, 2010; Esteve and Tamarit, 2012; Hamit- Haggar, 2012; Saboori et al, 2012; Chow, 2014). Following these studies, this work examines the validity of the EKC hypothesis using a quadratic function which relates the $CO_2$ emissions to GDP and GDP square. This is justified by the lack of empirical evidence on the validity of this hypothesis in developing countries and especially in the WAEMU countries. This quadratic function is expressed as follows:

$$\log CO_{2t} = \eta_0 + \eta_1 \log GDP_t + \eta_2 (\log GDP_t)^2 + \mu_t \tag{1}$$

$CO_2$ is the carbon dioxide (in kiloton), GDP is the real GDP and $\mu$ is the error term. All variables are in logarithms. Müller-Fürstenberger and Wagner (2007) have shown the limits of this environmental function. One of the main shortcomings of this function is the multicollinearity problem by using GDP and GDP square in one regression. At this time, there is no sufficient evidence, however, to recommend against the quadratic function in addressing the EKC. To check the robustness of the results in this study, equation (1) is expanded to include other variables such as trade openness (*openness*) and the share of industrial production to the GDP (*manuf*). The first variable takes into account the effect of the "pollution havens". There is evidence on the openness of the WAEMU economies following the economic liberalization in 1980. Moreover, these countries lack a framework of restrictive environmental regulation that can allow a migration of “dirty industries” from developed countries to the WAEMU countries. The second variable allows integrating the scale effect. The share of industrial production to the GDP is a proxy of the energy consumption and was also used in one study on Asian countries (Aspergis and Ozturk, 2015). More generally, energy structure and energy intensity are the two major driving forces of $CO_2$ emissions in Africa due to the high share of fossil fuel in total energy consumption and low penetration of clean energy as well as low energy efficiency (Lin et al, 2016). Finally, the function is expressed as follows:

$$\log CO_{2t} = \eta_0 + \eta_1 \log GDP_t + \eta_2 (\log GDP_t)^2 + \eta_3 \log openness_t + \eta_4 manuf_t + \mu_t \tag{2}$$

The inclusion of trade openness allows testing the hypothesis of technological displacement. Generally, under this hypothesis, it is assumed that trade openness causes the displacement of dirty industries from developed countries to developing countries. In other words, a positive effect of openness on pollution is expected ($\eta_3 > 0$). Moreover, higher industrial production is accompanied by higher energy consumption and pollution ($\eta_4 > 0$). Finally, the EKC hypothesis is confirmed if $\eta_1 > 0$ and $\eta_2 < 0$. Otherwise, the EKC hypothesis is not supported and U-shaped curve would be valid. However, Lind and Mehlum (2010) found that the sign of the parameters is only a necessary condition for the validity of a quadratic function. They propose the SLM test as sufficient condition of a quadratic relationship between income and pollution. Moreover, using energy consumption in $CO_2$ emissions model can lead to systematic volatility in its coefficients (Jaforullah and King, 2017). Therefore, this study uses SLM test for the purpose of robustness of the results.

Several techniques are used in the literature to estimate the above equations (see Table 1). In this study, the bound test technique developed by Pesaran et al. (2001) and based on the Autoregressive Distributed Lag (ARDL) model is used. This approach has been widely used in the literature of the EKC (see Table 1). Indeed, the bound test allows variables with different optimum lag. It allows for unbiased estimators even in the presence of endogenous variables (Harris and Sollis, 2003).

The bound test procedure consists of five steps (Pesaran et al, 2001; Jalil and Mahmud, 2009). The first is to examine the unit root test to avoid having variables with an integration order greater than two. The second step is to select the optimal number of lag. The third step verifies the existence of a long-term relationship between the variables. If the long term relationship is confirmed, then the fourth step estimates the coefficients of short and long term. Testing the stability of these coefficients is the final step of the bound test (Brown et al, 1975).The ARDL model derived from Equation (1) is written as follows:

$$\Delta(\log CO_{2t}) = \eta_0 + \eta_1 lco2_{t-1} + \eta_2 \log GDP_{t-1} + \eta_3 (\log GDP_{t-1})^2 + \sum_{i=1}^{p} \alpha_{1i} \Delta(\log CO_{2t-i}) + \sum_{i=0}^{q} \beta_{1i} \Delta(\log GDP_{t-i}) + \sum_{i=0}^{r} \delta_{1i} \Delta(\log GDP_{t-i})^2 + \mu_{1t} \quad (3)$$

$\Delta$ represents the first difference of the variables and the associated coefficients for the explanatory variables are the short-term coefficients while the other are the long-term coefficients. p, q and r, are the optimal lags and determined using the Akaike Information Criterion (AIC), the Schwarz criterion (SC), Hannan-Quinn criterion (HQC), the likelihood ratio (LR) statistic and the Akaike final prediction error (FPE).

Equation (3) is estimated with the ordinary least squares (OLS) technique. The test of the existence of a long-term relationship between the variables is based on the following assumptions: $H_0 : \eta_1 = \eta_2 = \eta_3 = 0$ and $H_1 : \eta_1 \neq 0, \eta_2 \neq 0, \eta_3 \neq 0$

The existence of co-integration is confirmed when the F-statistic is greater than the critical values of the bound test (Pesaran et al, 2001). If the co-integration is confirmed, then the coefficients of the long-term relationship are estimated (Equation 1). The residuals of this estimate are used to estimate the error correction model which is given as follows:

$$\Delta(\log CO_{2t}) = \sum_{i=1}^{p} \alpha_{1i} \Delta(\log CO_{2t-i}) + \sum_{i=0}^{q} \beta_{1i} \Delta(\log GDP_{t-i}) + \sum_{i=0}^{r} \delta_{1i} \Delta(\log GDP_{t-i})^2 + \psi mce_{t-1} + \mu_{1t} \quad (4)$$

$\psi$ is the adjustment speed in the event of impact in the short term

The robustness test is based on the Equation (2) whose ARDL model is written as follows:

$$\Delta(\log CO_{2t}) = \eta_0 + \eta_1 \log CO_{2t-1} + \eta_2 \log GDP_{t-1} + \eta_3 (\log GDP_{t-1})^2 + \eta_4 \log openness_{t-1} + \eta_5 manuf_{t-1} + \sum_{i=1}^{p} \alpha_{1i} \Delta(\log CO_{2t-i}) + \sum_{i=0}^{q} \beta_{1i} \Delta(\log GDP_{t-i}) + \sum_{i=0}^{r} \delta_{1i} \Delta(\log GDP_{t-i})^2 + \sum_{i=0}^{s} \phi_{1i} \Delta(\log openness_{t-i}) + \sum_{i=0}^{w} \varphi_{1i} \Delta(manuf_{t-i}) + \mu_{1t} \quad (5)$$

The estimation of the model follows the bound test procedure described above. Analysis of the co-integration is based on the following assumptions: $H_0 : \eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = 0$ and

$H_1 : \eta_1 \neq 0, \eta_2 \neq 0, \eta_3 \neq 0, \eta_4 \neq 0, \eta_5 \neq 0$

Beyond using additional variables for robustness, the Sasabuchi–Lind–Mehlum (SLM) U test is also used to test the sufficient condition of the existence of the EKC hypothesis.

Data on $CO_2$ emissions, GDP, the share of industrial value added in the GDP and trade openness are from the World Development Indicators (WDI 2015). All the variables used are in logarithms except the share of industrial value added in the GDP.

The unit root test was used to verify that the variables included in the model are I (0) or I (1) in accordance with the bound test approach. There are a variety of panel unit root tests. The results obtained with the augmented Dickey–Fuller (ADF) test show that the variables are I (1) in Benin and Mali (see Table 2). In this case, the Johansen cointegration and the bound test approaches are applicable. However, in Togo, *"manuf"* is I (0). Therefore, the bound test is appropriate.

Table 2. Unit root test

| Countries | Variables | level | L | First difference | L | Decision |
|---|---|---|---|---|---|---|
| Benin | $\log CO_2$ | -2.090 | 1 | -7.193*** | 0 | I(1) |
| | logGDP | -2.363 | 1 | -6.438*** | 0 | I(1) |
| | $(\log GDP)^2$ | -2.233 | 1 | -6.434*** | 0 | I(1) |
| | manuf | -1.612 | 1 | -6.063*** | 0 | I(1) |
| | logopenness | -1.610 | | -7.535*** | | I(1) |
| Mali | $\log CO_2$ | -3.486 | 1 | -6.551*** | 0 | I(1) |
| | logGDP | -0.666 | 1 | -6.596*** | 0 | I(1) |
| | $(\log GDP)^2$ | -0.586 | 1 | -6.603*** | 0 | I(1) |
| | manuf | -0.504 | 1 | -7.328*** | 0 | I(1) |
| | logopenness | -1.455 | | -5.242*** | | I(1) |
| Togo | $\log CO_2$ | -3.122 | 2 | -6.063 *** | 1 | I(1) |
| | logGDP | -3.368 | 1 | -6.415*** | 0 | I(1) |
| | $(\log GDP)^2$ | -3.341 | 1 | -6.398 *** | 0 | I(1) |
| | logopenness | -2.033 | 1 | -5.230 *** | 1 | I(1) |
| | manuf | -3.542** | 1 | -3.356 | 4 | I(0) |

Note: L= optimal lag. Phillips-perron test (not presented here) gives the same optimal lag.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

## 4. Results

This section presents the results of the bound test and the quadratic model estimates (sub-section 1) before the results of the robustness checks (sub-section 2).

### *4.1 The Bound Test Results and Estimates*

The first step of the bound test is to test the existence of co-integration between variables. The results indicate that there is a long-term relationship between the variables in the three countries (see Table 3). Indeed, the F-stat in the three cases exceeds the critical values of the bound test.

Table 3. Bound test results

| | L | F-statistics | Decision | Low bound 5% | Upper bound 5% |
|---|---|---|---|---|---|
| Benin | 2 | 6.091 (0.002) | Co-integration | 3.79 | 4.85 |
| Mali | 0 | 6.487 (0.001) | Co-integration | | |
| Togo | 1 | 5.918 (0.002) | Co-integration | | |

Note: The values in parentheses are probabilities. L= optimal lag obtained using AIC, SC, LR, FPE and HQC criteria. Bound test values are obtained from table CI (iii) Case III: Unrestricted intercept and no trend pour k=2.

The long-term relationship coefficients show that in the three countries the results are significant except the case of Togo where the variable GDP square is not significant (see Table 4). Furthermore, an increase by 1% in GDP corresponds to a decrease by 24.3% in $CO_2$ emissions in Benin and an increased of $CO_2$ emissions of 29.5% in Mali and 37.7% in Togo. In addition, the negative and significant effect of the GDP square on the $CO_2$ emissions in Mali confirms the existence of an inverted U-shaped relationship between GDP and $CO_2$ emissions. In the case of Benin, however, the positive and significant effect of the GDP square confirms a U-shaped relationship. The diagnostic tests show that there is neither serial correlation problem (LM test) nor heteroskedasticity.

Table 4. Long term coefficients

| **Variables** | **Benin** | **Mali** | **Togo** |
|---|---|---|---|
| C | 249.403*** (0.000) | -324.291*** (0.000) | -411.250* (0.076) |
| logGDP | -24.32852*** (0.000) | 29.52767*** (0.000) | 37.72438* (0.085) |
| $(logGDP)^2$ | 0.60608*** (0.000) | -0.659172*** (0.000) | -0.849 (0.100) |

| | | | |
|---|---|---|---|
| Diagnostic tests | **Adjusted R$^2$**=0.971<br>**DW**=1.828<br>**LM test**:<br>F=0.768(0.761)<br>**Heteroskedasticity test**:<br>F=0.180(0.835) | **Adjusted R$^2$**=0.933<br>**DW**=2.815<br>**LM test** :<br>F=1.763(0.672)<br>**Heteroskedasticity test**:<br>F=1.892 (0.200) | **Adjusted R$^2$**= 0.821<br>**DW**=2.231<br>**LM test** :<br>F=0.267(0.767)<br>**Heteroskedasticity test**:<br>F=1.067(0.353) |

Note: The values in parentheses are probabilities *** p<0.01, ** p<0.05, * p<0.1

The estimated coefficients of the long-term generate residuals that are used to develop the error correction model. The results are given in Table 5. In this case, the results of the Wald test show that there is joint significance of the estimated coefficients in the short term in Benin and in Mali but this is not confirmed in the case of Togo. However, in the long-term, all the variables affect significantly $CO_2$ emissions. Indeed, the adjustment speed in the equilibrium relationship is negative and significant at 1%. Its coefficient is -0.668 in Benin, -0.393 in Mali and -1 in Togo. Moreover, the diagnostic tests show that the error correction model is valid for the three countries.

Table 5. Short term coefficients

| Variables | **Benin** | **Mali** | **Togo** |
|---|---|---|---|
| C | 0.044<br>(0.316) | 0.020**<br>(0.047) | 0.048<br>(0.203) |
| $\Delta \log co2_{t-1}$ | 0.216<br>(0.268) | - | 0.088<br>(0.612) |
| $\Delta \log co2_{t-2}$ | 0.133<br>(0.421) | - | - |
| $\Delta \log GDP_{t-1}$ | 65.425<br>(0.197) | 24.214***<br>(0.003) | 23.417<br>(0.728) |
| $\Delta \log GDP_{t-2}$ | -73.576<br>(0.148) | - | - |
| $\Delta(\log GDP)^2{}_{t-1}$ | -1.503<br>(0.205) | -0.444***<br>(0.004) | -0.564<br>(0.723) |
| $\Delta(\log GDP)^2{}_{t-2}$ | 1.691<br>(0.155) | - | - |
| $ect(-1)$ | -0.668***<br>(0.005) | -0.393***<br>(0.000) | -1.008***<br>(0.000) |
| Diagnostic tests | **Adjusted R$^2$**=0.289<br>**LM test**: F=1.565(0.226)<br>**Heteroskedasticity test**:<br>F=0.829(0.571)<br>**Wald test** :<br>F= 2.190(0.094) | **Adjusted R$^2$**=0.040<br>**LM test**: F=0.116(0.890)<br>**Heteroskedasticity test**:<br>F=0.993(0.407)<br>**Wald test** :<br>F=9.183(0.000) | **Adjusted R$^2$**=0.441<br>**LM test** :<br>F=0.424 (0.657)<br>**Heteroskedasticity test**:<br>F=0.414(0.100)<br>**Wald test**:<br>F= 0.250 (0.780) |

Note: The values in parentheses are probabilities *** p<0.01, ** p<0.05, * p<0.1

The stability test (cusum and cusumQ) shows that the error correction model (ECM) is structurally stable in the three countries but occasionally unstable in Togo and Mali over the period 1980-2000 (see appendix 1).

*4.2 Robustness Checks*

The robustness analysis consisted on the one hand, to increase the number of control variables and to test the sufficient condition of the EKC hypothesis proposed by Lind and Mehlum (2010), on the other hand.

After determining the optimal lag (L) for each country, the ARDL model (Equation 5) is estimated. The results of the bound test show that the long term relationship exists only in the case of Mali. Indeed, the F-stat (5.52) is higher than the critical values of the bound test at the 5% threshold (see Table 6). Thus, the following bound test steps were limited to that country.

Table 6. Bound test results

| Countries | L | F-statistics | Decision | Low bound 5% | Upper bound 5% |
|---|---|---|---|---|---|
| Benin | 2 | 2.613 (0.053) | No co-integration | 2.86 | 4.01 |
| Mali | 0 | 5.527 (0.001) | Co-integration | | |
| Togo | 1 | 2.684 (0.042) | No co-integration | | |

Note: The values in parentheses are probabilities. L= optimal lag obtained using AIC, SC, LR, FPE and HQC criteria. Bound test values are obtained from table CI (iii) Case III: Unrestricted intercept and no trend, k=4.

In the case of Mali, the long-term coefficients and those of the short-term were estimated and reported (see Table 7). The results show that despite the addition of control variables, the signs of the coefficients remain identical and significant with those of equation (1) but with higher effects. Indeed, the effect of the GDP on the $CO_2$ emissions is 31.39 while that of GDP square is -0.70. Therefore, the assumption about the existence of the EKC cannot be rejected. Moreover, the effect of openness is positive and significant while the share of manufacturing value added (*manuf*) in the GDP is negatively related to $CO_2$ emissions.

The Wald test results indicate that the short term coefficients are valid. This test confirms the significant effect of the adjustment speed at the 1%. It is the same for the long term coefficients. Indeed, any short-term shock causes an adjustment to long-run equilibrium. The adjustment speed (-0.55) is negative and significant at the 1%. Finally, the diagnostic test indicates that the results are valid.

Table 7. Short term and long term coefficients (case of Mali)

| Short term coefficients | | Long term coefficients | |
|---|---|---|---|
| Variables | Coefficients | Variables | Coefficients |
| C | 0.002<br>(0.807) | C | -344.601***<br>(0.000) |
| $\Delta \log GDP$ | 29.566***<br>(0.000) | $\log GDP$ | 31.390***<br>(0.000) |
| $\Delta(\log GDP)^2$ | -0.660***<br>(0.000) | $(\log GDP)^2$ | -0.703***<br>(0.000) |
| $\Delta \log openness$ | 0.217***<br>(0.000) | $\log openness$ | 0.214***<br>(0.006) |
| $\Delta manuf$ | 1.089<br>(0.200) | $manuf$ | -1.589**<br>(0.010) |
| $ect(-1)$ | -0.552***<br>(0.000) | | |
| **Adjusted R$^2$**=0.471<br>**LM test**:<br>F=3.005(0.063)<br>**Heteroskedasticity test**:<br>F=0.499 (0.774)<br>**Wald test**:<br>F= 8.455( 0.000) | | **Adjusted R$^2$**=0.946<br>**LM test**:<br>F=3.745(0.033)<br>**Heteroskedasticity test**:<br>F=1.847(0.141) | |

Note: The values in parentheses are probabilities. *** p<0.01, ** p<0.05, * p<0.1

In terms of stability coefficients, cusum tests and cusum squared indicate that the model is stable over the analysis period (see Appendix 2). Finally, the results of the SLM test confirm the existence of the EKC in Mali and the turning point at an income per capita equals 22.31 billion US dollars (see Table 8). This value is in logarithmic. Thus, the income corresponding to the turning point of income per capita is $ 436.22 us (constant 2005).

Table 8. SLM test

| | Lower bound | Upper bound |
|---|---|---|
| Interval | 21.237 | 22.665 |
| Slope | 1.513 | -0.494 |
| t-value | 11.332 | -4.267 |
| P>t | 9.92e-14 | 0.000 |
| Extremum point: **22.313**<br>t-value = 4.27<br>P>\|t\| = 0.000 | | |

## 5. Discussion

The results obtained with the Equation (1) show that the variables have a short and long term effect on the level of pollution in Benin and Mali while in Togo this effect is only valid in the long term. In the case of Benin, environmental curve is a U-shaped. Indeed, the positive and significant effect of the GDP square indicates a non-monotonic relationship between GDP and $CO_2$ emissions. However, the Kuznets hypothesis is confirmed only in the case of Mali given the negative and significant effect of the GDP square on the $CO_2$ emissions. This implies that economic growth in Mali reached the turning point where it would contribute to reduce pollution. The result is in line with those found in Sub-saharan Africa (Orubu and Omotor, 2011; Osabuohien et al, 2014.), in Spain (Esteve and Tamarit, 2012), in Canada (Hamit-Haggar, 2012) and in Malaysia (Saboori et al, 2012) but contrast with those found by Robalino-López et *al* (2015) in Venezuela. Most of the studies that confirm the existence of the EKC is related to developed countries. Therefore, the result found here seems paradoxical in the sense that economic growth is relatively low in Mali and with respect to the turning point which is 436 $US in the GDP per capita term. Indeed, for the most indicators used as a proxy of pollution, the turning point is at a level of GDP per capita between 3000 and 10,000 $ US in constant 1985 prices (Dinda, 2004). However, the result found here is supported by Narayan et al (2016). Based on the cross-correlation coefficient (CCC) between real GDP per capita and carbon dioxide emissions, they found that Mali is one of the low-income countries where there is evidence for an inverted U-shaped relationship. The first explanation of the result found in Mali is that the environmental policies were in favor of less polluting behaviors. However, the positive and significant effect of the openness confirms the "pollution havens" hypothesis. Indeed, more openness results in increased levels of pollution.

The validity of the PHH in Mali implies that openness promotes the movement of polluting industries from developed to developing countries (Mali). In the case of Vietnam, Al-Mulali et al (2015) found that the pollution havens hypothesis is invalid while the result of the present work is in line with those of other studies (Lucas et al, 1992; Birdsall and Wheeler, 1993). These authors found that the period of high intensity of pollution in developing countries corresponds to the period when the OECD countries have strengthened their environmental regulation. The lack of restrictive environmental regulation seems to be the cause of the transfer of polluting industries from developed to developing countries. Moreover, the result found in Mali could be explained by structural adjustment programs due to the instability of the model during the period 1980-2000 (see cusum square test in Appendix 2).

The robustness tests confirm the existence of the EKC hypothesis in the case of Mali. The previous results remain valid despite the inclusion of other control variables. The SLM test confirms the validity of the quadratic relationship. The coefficient of the adjustment speed indicates that 55.2% of imbalance is corrected in the first period.

In addition, the results indicate that an increase in the share of manufacturing value added to the GDP (proxy of energy consumption) of a percentage point is associated with a decrease in $CO_2$ emissions by 1.58%. This result seems counter-intuitive in the sense that an important industrial production corresponds to higher energy consumption and more pollution. However, a negative relationship between the level of energy consumption and $CO_2$ emissions was also found in Nigeria (Wolde-Rufael, 2005), in Saudi Saoudhite and United

Arab Emirates (Squalli, 2007) and in USA (Bowden and Payne, 2009). It is recognized that growing economies like Mali move towards less energy-intensive production sectors (Squalli, 2007). For example, the data obtained from the World Development Indicators (WDI 2015) show that the proportion of agricultural value added in GDP was 54.4% from 1970 to 1985 but decreased to 42.6% between 1985 and 2009. In the same time, the industrial sector added value over GDP increased from 12.6% to 19.3% and the service sector from 32.8% to 38%. However, the service sector is less energy-intensive than industrial sector (Winkler, 2007). This could explain the lower level of pollution in Mali despite the low level of income reached. Al-Mamun et *al* (2014) found that the economic transformation of the industrial sector to the service sector has led to a reduction of $CO_2$ emissions in countries with low and middle incomes.

## 6. Conclusion and Policy Implications

The objective of this study was to investigate the existence of the EKC relationship between income and $CO_2$ emissions in the WAEMU countries over the period 1970 to 2010. To that end, the quadratic function was used and estimated with the bound test approach. The panel co-integration test indicates that there is no co-integration relationship between GDP and $CO_2$ emissions. This confirms the relevance of using individual country data in analyzing the relationship between income and pollution. Thus, for countries such as Benin, Mali and Togo, the results show a long-term relationship between these variables. Therefore their estimates were only reported and analyzed.

The results indicate that GDP has a short and long term effect on $CO_2$ emissions in Benin and Mali, while in Togo this effect is only valid in the long term. In addition, the EKC hypothesis is confirmed only in Mali, while in Benin, GDP has a U-shaped effect on pollution. The case of Togo is not conclusive. The robustness tests have been carried out for the three countries.

The results of robustness checks confirm the existence of the EKC hypothesis in Mali. Moreover, the results show that the quadratic relationship between GDP and $CO_2$ emissions is valid in the case of this country. Thus, the estimated coefficients indicate that GDP affects $CO_2$ emissions in the short and long term. These results imply that Mali reached the turning point where economic growth contributed to reduce pollution. This result, which seems paradoxical for a developing country like Mali would be linked to the country's economic transformation over the period 1985 to 2009. This period was marked by growth in the service sector which is less polluting than industrial sector. This would have contributed to the decrease in $CO_2$ emissions. Nevertheless, the validity of the "pollution havens" hypothesis shows that the government of Mali may strengthen its environmental regulation policy to limit the influx of polluting industries in the country. Although the importance of collective actions in mitigating pollution, countries individual initiatives in the WAEMU are also relevant as per the result. As low-income economies, the WAEMU countries cannot, however, rely solely on their economic growth to further reduce $CO_2$ emissions.

This study focused on quadratic function and used $CO_2$ emissions only as an indicator of pollution. However, using other indicators of pollution and testing linear function are also necessary when investigating the relationship between income and pollution. Therefore, these issues deserve further attention in future researches on the WAEMU countries.

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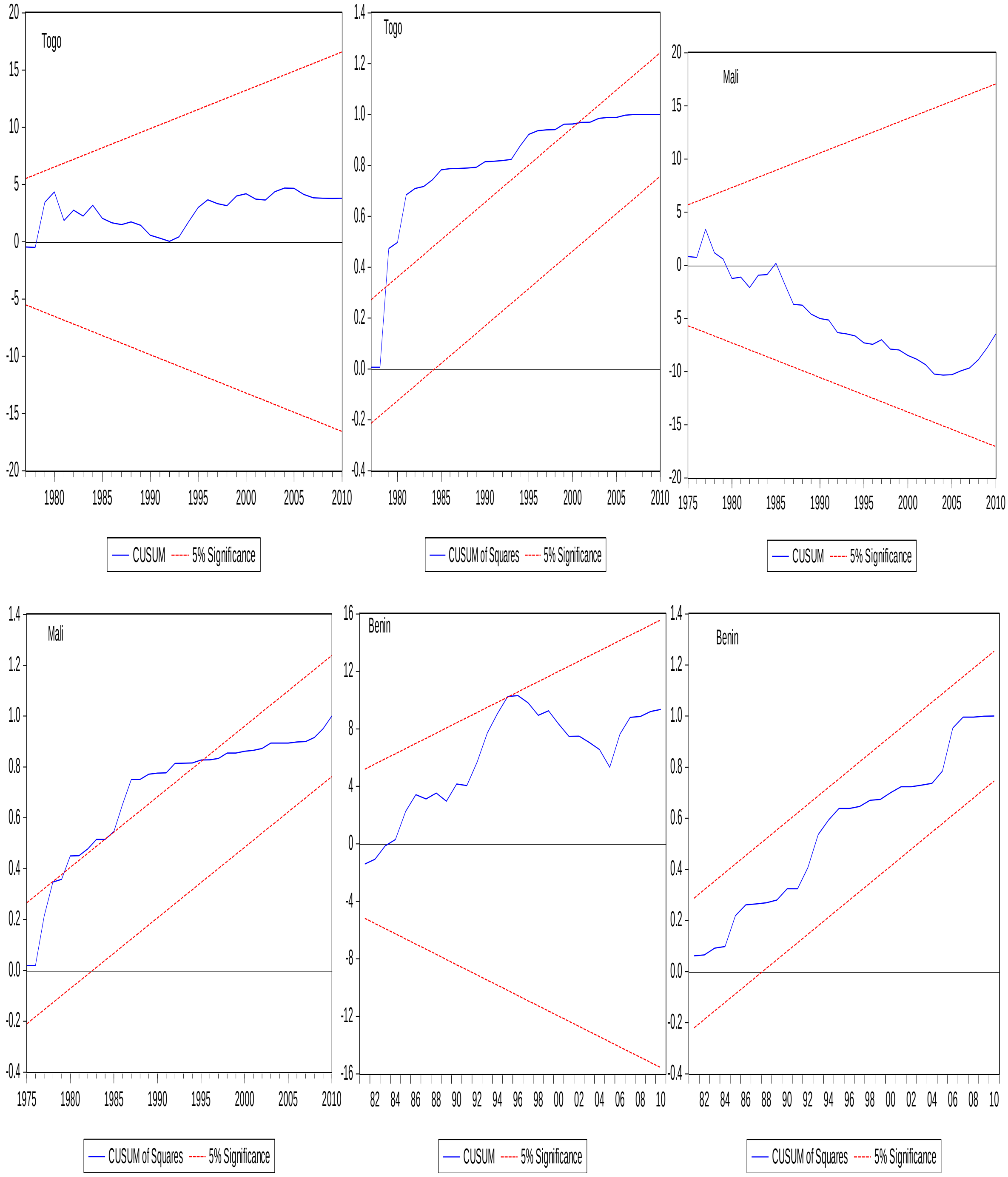
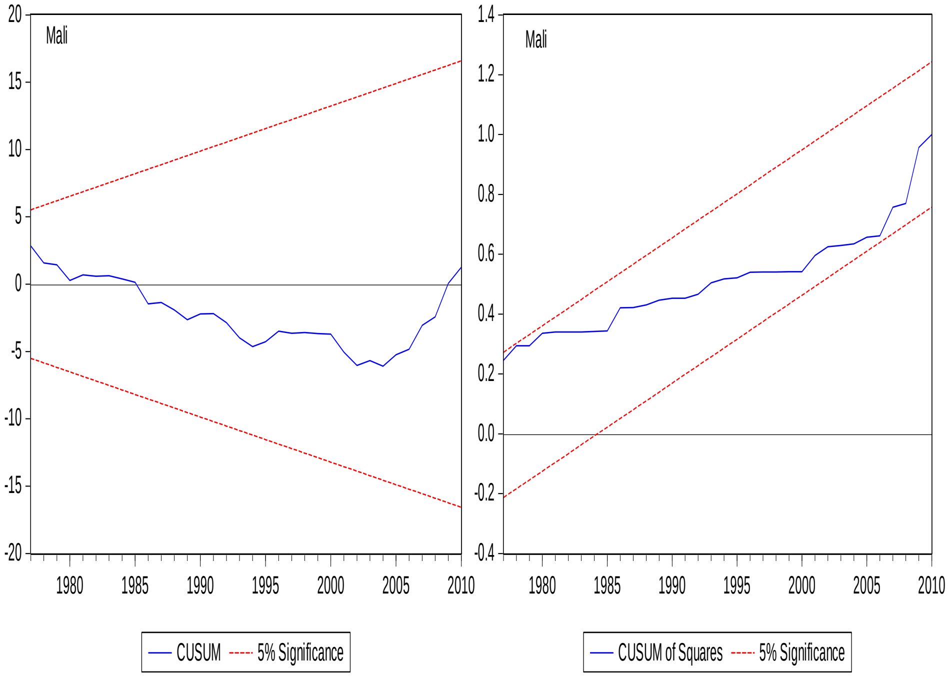
## Appendices

Appendix 1. Stability test of the ECM from equation (1)



Appendix 2. Stability test of ECM from equation 2 (case of Mali)

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