The environmental Kuznets curve hypothesis for CH_4 emissions: evidence from ARDL bounds testing approach in Argentina

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Abstract: This paper investigates the relation among CH_4 emissions and gross domestic product of Argentina with two additional variables such as electricity power consumption and agriculture land use trying to prove the existence of the environmental Kuznets curve. Our main results are as: 1) there is an environmental Kuznets curve in Argentina; 2) there is long run relationship among the variables; 3) CH_4 emissions has positive relation with gross domestic product; 4) electric power consumption and agriculture use have positive effect on the gross domestic product of Argentina; 5) there is no short run relationship among the variables according to Granger causality test results in the model 1, model 2 presents bi-causality among CH_4 emissions and agriculture use. Further, several recommendations were formulated to continue with undertake any conservative policy in order to reduce emissions without major consequences on economic sectors.

Keywords: environmental Kuznets curve; EKC; methane emissions; electricity power consumption; agriculture land use; autoregressive distributed lag; ARDL; Argentina.

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1 Introduction

Climate change characterised by global warming has already had observable impact on the ecological system and human society (Alley et al., 2003). This warming trend is expected to continue in the forthcoming decades and would impose even more significant impact on ecosystem and human society (IPCC, 2013). There are several contributions in which the positive and significant relationship between environmental degradation and economic growth is defined, and within this field the environmental Kuznets curve (EKC) has been prevalent in the work of several researchers. It is subject of constant discussion, the election of the proxy variable that replaces the environmental degradation on EKC estimations. There are several studies in which carbon dioxide (CO_2), nitrous oxide (N_2O) emissions are used, however, there are limited contributions that use methane (CH_4). Based on this, we propose to cover the existing literature, imposing as main variation the choice of the dependent variable (CH_4 emissions) that within the theoretical framework of the EKC has been widely covered by CO_2 emissions, N_2O emissions and other polluting gases. Modern intensive farming, which heavily depends on chemical fertiliser application and irrigation, is the single largest source of CH_4 emissions (IPCC, 2014; FAO, 2016).

CH_4 emissions are the second biggest greenhouse gas (GHG) emissions in the world (IPCC, 2014) and they are generated, principally, because of agriculture and livestock farming activities. Argentina is one of the biggest producers of meat in the region (Obschatko et al., 2015) with around 51 million of cattle. Agriculture is the third principal economic activity with around 10% of the total gross domestic product.

Argentina has greatly improved its record of economic growth and poverty since the 2001 financial crisis, although development has not always been sustainable and friendly to the environment (World Bank, 2016). The Argentine economy, one of the largest in Latin America, is endowed with valuable natural resources. During the last decade, the economy grew steadily, more people managed to enter the middle class, and inequality decreased. The background of the country in environmental management is varied. The loss of forest cover remains a challenge (representing 9.7% of the country's surface in 2015, compared to 12.5% in 1990), and this is mainly due to the continued expansion of agriculture to industrial scale.

GHG emissions have increased steadily in Argentina and the energy sector has become the single largest contributor. Emissions from the energy sector represent 43% of total GHG emissions; the agricultural sector, land use change and forestry make up almost half of total emissions in Argentina (CAIT, 2017). In the country, thermal energy prevails (60% of the total), followed by hydroelectricity (35%). The sectors of transport, industrial residence consume each approximately 26% of the total energy. In the case of Argentina, there is a strong stance from environmental organisations that demand more stringent reduction targets for agricultural GHG emissions (Iñigo-Carrera, 2017) and the prescriptions of obligatory climate protection programs with corresponding measures for agriculture (Secretaría de Ambiente y Desarrollo Sustentable, 2017). Argentine' demand for energy has grown per year, because of that, it is expected that energy demand will continue to grow in the future in parallel to country's economic growth, for this reason has included the consumption of electricity within this study.

Thus, there is the need to explore the joint behaviour between economic growth and CH_4 emissions in order to establish energy and agricultural policies that strike a balance between economic growth and environmental prosperity (Narayan and Narayan, 2010).

The framework of analysis is by testing the EKC hypothesis. The EKC hypothesis asserts that as national or regional output increases, GHG emissions increase until a threshold level of output is reached, after which emissions decline and environmental conditions improve. The testing approach consists of estimating autoregressive distributive lag (ARDL) bounds and cointegration models. The ARDL approach has been used in similar settings to test the EKC hypothesis; for example, it was used to analyse the potential of renewable energy sources in reducing the impact of GHG emissions in Turkey (Bölük and Mert, 2015) and examining the impacts of income, energy consumption and population growth on carbon dioxide (CO_2) emissions in India, Indonesia and China (Soytas and Sariab 2009).

This document establishes as a main assumption that there is a causal relationship between methane emissions and economic growth (measured through the gross domestic product), evidently their relationship is limited to our findings through empirical evidence. Our idea to establish this relationship is subject to the fact that agricultural activities provoke the increase of methane emissions (Mosier et al., 1998; Yan et al., 2009), in turn there is a significant contribution of agricultural activities to economic growth (Diao, 2010), therefore, the fact that agricultural activities affect the economic growth establishes a connection between economic growth and methane emissions.

As previously understood, both the electric consumption (ELC) and agricultural development in Argentina have an impact on environmental degradation and economic growth, therefore, those are the reasons that motivate us to study the Argentinian case and found the existence of an EKC for the period of 1970 to 2012.

There are no previous studies of the EKC evaluation in Argentina, so our results are oriented to the policy makers consider our findings to formulate policies more friendly to the environment. The rest of the paper is organised as follows. Section 2 presents the literature review of EKC studies which especially include variables used in our study. Section 3 describes the estimation procedure and data of our analysis. Section 4 discusses the empirical results and compares the results of the analysis with previous studies. Concluding remarks are given in the Section 5 and the final section exposes the limitations of this research and issues considerations for future research.

2 Literature review

In the environmental context, CO_2 emissions are the GHG most produced because of the human activity, but in this paper we're going to focus on the second GHG most emitted, CH_4 emissions. CH_4 emissions, in general, are generated as a result of anthropogenic activities, principally agriculture. According to the World Bank (2017a) Argentina and Brazil are the countries with most emissions of methane and that is caused by livestock farming activities. Argentina and Brazil are also the countries with most production of meat in the region.

Agriculture and livestock farming contribute with 44% of total GHG emissions in the country, just behind energy sector (Berra and Finster, 2003) and 48% of total methane emissions. From the percentage of total GHG emissions, 30% comes from livestock farming, especially from cattle that contributed with 95% of it (Obschatko et al., 2015). Livestock farming contributes to the methane emissions from enteric fermentation and excretions of animals. These two last are also a source of nitrous oxide, just as nitrogen-fixing fodder. In agricultural activities, these emissions occur as a result of nitrogen-fixing crops, including soybeans and stubble. Commercial fertilisers also contribute to the emission nitrous oxide, while rice cultivation generates methane emissions. Finally, burning stubble produces nitrous oxide emissions, other nitrogen oxides, carbon monoxide and methane.

Even though methane is the second largest GHG in Argentina, its emissions have been reduced as a result of an increase in the technology used in agriculture and livestock farming. Innovated processes and changes in macroeconomics policies led to rural population to begin a process of economic, productive and social recovery. This growth is accompanied by sustainable development policies for agricultural and rural sector. The agri-food and agribusiness strategic plan (PEA, 2010) and the smart agriculture plan (World Bank, 2017b) were created in order to generate a more efficient, competitive and sustainable production. Promoting smart agriculture involves developing active policies in the agricultural sector to harmonise production and environmental systems, at the same time it is representing Argentine government's response to the challenge of security food in a context of climate change.

There are several studies that estimate the relationships between electricity consumption and economic growth, there are studies in which causality has been found between the consumption of electricity and economic growth (Bildirici and Kayıkçı, 2012), there are also studies who found causality from economic growth to electricity consumption (Iyke, 2015), there are studies in which bi-causality has been found between the consumption of electricity and economic growth (Hu and Lin, 2008), and finally studies where there is no causal relationship between these variables (Yoo and Kwak, 2010), however, enough literature allows us to use electricity consumption in modeling the EKC, because its influence on environmental degradation can be significant because the population increase causes greater electricity consumption which can lead to environmental damage (Al-mulali et al., 2014; Golam Ahamad and Nazrul Islam, 2011; Narayan and Prasad, 2008; Ho and Siu, 2007).

3 Model and estimation procedure

3.1 Data

The variables used are: CH_4 emissions (CH_4) measured in metric tons per capita; income (GDP) using per capita real GDP in constant 2010 US$; agriculture land use (AGR) is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources; and ELC is expressed in terms of billion kilowatt hours (kWh). These variables are obtained from World Bank Development Indicators (World Development Indicators, The World Bank, 2017).

3.2 Econometric model

We proposed two models, following our empirical hypothesis, it is possible to test whether there is a long run relationship between CH_4 emissions, gross domestic product, and electricity power consumption in a quadratic form for the model 1. In the model 2 we test whether there is a long run relationship between CH_4 emissions, gross domestic product, and agricultural land use also in a quadratic form. To test the validity of EKC hypothesis the following two equations has been defined and employed for the models:

$$\mathrm{CH}_{4t} = \beta_0 + \beta_1 \mathrm{GDP_t} + \beta_2 \mathrm{GDP}_t^2 + \beta_3 \mathrm{ELCt} + \mathrm{u_t} \tag{1}$$

$$\mathrm{CH}_{4t} = \beta_0 + \beta_1 \mathrm{GDP_t} + \beta_2 \mathrm{GDP}_t^2 + \beta_3 \mathrm{AGR_t} + \mathrm{u_t} \tag{2}$$

In equation (1), CH_4 is the methane emissions per capita (measured in thousand metric tons per capita) as a proxy for pollution, GDP is per capita gross domestic product (in constant 2010 US Dollar), GDP^2 is the square of GDP, ELC stands for the electric power consumption measures the production of power plants and combined heat and power plants less transmission, distribution, and transformation losses and own use by heat and power plants, and finally u is disturbance term. The model 2 [equation (2)] have a similar structuration with the variation of AGR variable that corresponds to ISIC divisions 1–5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production in constant 2010 US dollars. Under the EKC hypothesis, coefficient β_1 is expected positive sign and the coefficient β_2 is expected negative sign. That the coefficient β_1 is positive means that the greater economic growth provokes greater methane emissions. At the same time, that the coefficient β_2 is significant and negative means that there is a turning down point on the curve.

At this point, increasing economic growth begins to make methane emissions reduction. In this situation, the turning point of GDP is calculated to be $\beta_1/(2\beta_2)$. As for the expected sign of the other explanatory variable ELC, one expects the coefficient β_3 to be negative since the electric power consumption displaces emissions of GHGes from the combustion of fossil fuels. Moreover, it is a condition of the EKC validation. AGR is expected to have a positive relationship with CH_4 emissions as they are a source that increases emissions.

3.3 Estimation procedure and ARDL

We employ the ARDL technique, commonly known as ARDL bound tests given by Pesaran et al. (2001). A quality of this technique is that can be used whether variables are purely I(0), purely I(1) or the mixture of both I(0) and I(1) (Pesaran and Shin, 1998). Additionally, it captures appropriate number of lags in data generating process particularly in general to specific process as is reported by Laurenceson and Chai (2003) and the error correction model (ECM) can be obtained from bound testing approach through simple OLS transformation. ECM shows short run to long run adjustment mechanism without the loss of long run information.

In case of some endogenous regressors, ARDL approach provides unbiased estimates in the long run (Narayan, 2005). To avoid endogeneity problem, researchers introduce instrumental variables, and however, there is no ideal instrument. To solve this problem, it could be introduced the lags of variables by making the model dynamic (Borensztein et al., 1998). According to Ouattara (2004), we cannot use ARDL if any of the variable under investigation is stationary at second difference, i.e., I(2) as bound testing approach is based on I(0), I(1) or mixture of these two sets. Owing this reason, we check the unit root property of each variable to confirm that any of the variables should not be stationary at second difference. For this, we use ADF (Dickey and Fuller, 1979b, 1981) and PP (Philllips et al., 1988) unit root tests. Basically, ARDL to cointegration approach is based on two steps to explore the long run association among the variables under investigation (Layson, 1983). ARDL method has been used in many studies and in the current study. Therefore, this technique has been used to obtain the long run relationship among the series. Data is transformed in logarithmic form as it provides efficient, better and consistent results (Cameron, 1994; Ehrlich, 1996). The logarithmic form of the data does not only make the data smooth but also overcome the heteroskedasticity issue (Boutabba, 2014).

The model 1 is given below.[1]

$$CH_4 = F\left(GDP, GDP^2, ELC\right) \tag{3}$$

The functional form of the model will be as equations (1) and (2), and can be rewritten as an ARDL formula as the model with intercept in equation (4) and the model with intercept and trend equation (5) as is shown next:

$$\begin{aligned}\Delta \ln CH_{4t} = {} & \alpha_0 + \sum_{i=1}^{m} \beta_{1i} \Delta \ln CH_{4t-i} + \sum_{i=0}^{m} \beta_{2i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{m} \beta_{3i} \Delta \ln GDP_{t-i}^2 \\ & + \sum_{i=0}^{m} \beta_{4i} \Delta \ln ELC_{t-i} + \beta_5 \ln CH_{4t-1} + \beta_6 \Delta \ln GDP_{t-1} + \beta_7 \Delta \ln GDP_{t-i}^2 \\ & + \beta_8 \ln ELC_{t-1} + v_t \end{aligned} \tag{4}$$

$$\begin{aligned}\Delta \ln CH_{4t} = {} & \alpha_0 + \alpha_1 t \sum_{i=1}^{m} \beta_{1i} \Delta \ln CH_{4t-i} + \sum_{i=0}^{m} \beta_{2i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{m} \beta_{3i} \Delta \ln GDP_{t-i}^2 \\ & + \sum_{i=0}^{m} \beta_{4i} \Delta \ln ELC_{t-i} + \beta_5 \ln CH_{4t-1} + \beta_6 \Delta \ln GDP_{t-1} + \beta_7 \Delta \ln GDP_{t-i}^2 \\ & + \beta_8 \ln ELC_{t-1} + v_t \end{aligned} \tag{5}$$

To check the existence of a long-run relationship among the variables is examined by Bounds test. According to the test, null hypothesis which implies no cointegration is H_0: $\beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$ against the alternative hypothesis H_0: $\beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$. If the calculated F statistic is higher than the upper bound critical value I(1) for the number of explanatory variables (k) by Pesaran et al. (2001), null hypothesis will be rejected. If the F statistic is lower than the lower bound critical value I(0), null hypothesis cannot be rejected. The F statistic being between I(0) and I(1)puts for than indecision about cointegration. Narayan (2005) suggested alternative critical values I(0) and I(1) which are more appropriate than that of (Pesaran, Shin, and Smith 2001) for small sample sizes. Optimal lag value m in equations. (4) and (5) is chosen based on the model selection criteria such as Akaike (AIC) or Schwarz (SIC) information criteria. The minimum AIC or SIC of the model implies optimal m. Besides, there must be no serial correlation in residuals for the model. If there is a cointegration, next step of ARDL process holds the long-run ARDL equation as is shown next:

$$\Delta \ln CH_{4t} = \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta \ln CH_{4t-i} + \sum_{i=0}^{q} \beta_{2i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{r} \beta_{3i} \Delta \ln GDP_{t-i}^{2} + \sum_{i=0}^{s} \beta_{4i} \Delta \ln ELC_{t-i} + \varepsilon_t \quad (6)$$

To select the lag values p, q, r and s in equation (6), model selection criteria such as AIC, SIC, Hannan-Quinn information criteria are used. The best estimated model is the model which has the minimum information criteria. Finally, short-run estimation of ARDL model also known as error-correction model is estimated in the equation below

$$\Delta \ln CH_{4t} = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta \ln CH_{4t-i} + \sum_{i=0}^{q} \delta_{2i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{r} \delta_{3i} \Delta \ln GDP_{t-i}^{2} + \delta \sum_{i=0}^{s} \beta_{4i} \beta_{4i} \Delta \ln ELC_{t-i} + \lambda ECM_{t-1} + \tau_t \quad (7)$$

The coefficient of the error-correction term (ECM_{t-1})λ in equation (7) is the speed of adjustment parameter which shows how quickly the series attain a long-run equilibrium. The expected sign of this coefficient is negative and it is also expected significant. Diagnostic tests such as serial correlation, normality, functional form, heteroscedasticity tests are conducted to ensure the acceptability of the model. Besides, stability test such as cumulative sum (CUSUM) and cumulative sum of squares (CUSUMQ) by Brown et al. (1975) are done to see the stability of the coefficients on the graphical representations.

In the final stage, we use the vector error correction model (VECM) to check the causal relationship among the variables after the cointegration relationship was verified among the series. Since the variables are I (1) the application of the VECM approach is appropriate to examine causality (Engle and Granger, 1987). Equation (8) details the VECM Granger causality specification:

$$\begin{pmatrix} \Delta \ln CO2_t \\ \Delta \ln GDP_t \\ \Delta \ln GDP^2{}_t \\ \Delta \ln ELC_t \end{pmatrix} = \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{pmatrix} + \sum_{l=1}^{m} \begin{pmatrix} \theta_{1,1} & \theta_{1,2} & \theta_{1,3} & \theta_{1,4} \\ \theta_{2,1} & \theta_{2,2} & \theta_{2,3} & \theta_{2,4} \\ \theta_{3,1} & \theta_{3,2} & \theta_{3,3} & \theta_{3,4} \\ \theta_{4,1} & \theta_{4,2} & \theta_{4,3} & \theta_{4,4} \end{pmatrix} \begin{pmatrix} \Delta \ln CO2_{t\text{-}k} \\ \Delta \ln GDP_{t-k} \\ \Delta \ln GDP^2{}_{t-k} \\ \Delta \ln ELC_{t-k} \end{pmatrix} + \begin{pmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \end{pmatrix} ECT_{t-1} + \begin{pmatrix} \omega_{1,t} \\ \omega_{2,t} \\ \omega_{3,t} \\ \omega_{4,t} \end{pmatrix} \quad (8)$$

where the error vector is distributed normally with mean zero and time-constant variance. According to Masih and Masih (1997) and Shahbaz et al. (2014), both short-term and long-term relationships can be determinate with a VECM, in the long run by statistical significance of coefficient of lagged error term ECTt−1using t-statistic and in the short run by statistical significance of F-statistic using Wald-test by incorporating differenced and lagged differenced of independent variables in the model.

Table 1 Descriptive statistics

	CH_{4t}	GDP_t	ELC_t	AGR_t
Mean	0.002	8,288.71	7.865	1,674.78
Maximum	0.003	12,011.72	11.953	2,954.54
Minimum	0.002	6,201.87	4.815	870.62
Std. dev.	0.000	1,347.84	1.882	614.89

4 Results

In order to test the presence of stochastic stationary in data, firstly the integration of time series has been investigated. For the test ADF, Schwarz information criteria has been used to decide lag length. Bartlett Kernel estimation method with Newey-West bandwidth has been used in the test of PP. Unit root tests for the first differences of the variables CH_4, GDP, GDP^2, ELC and AGR are given in Table 2. Augmented Dickey-Fuller (Dickey and Fuller, 1979a) and Philips and Perron (Philllips et al., 1988) unit root tests indicate that all the variables are not stationary at levels. However, variables are found to be stationary after first differences. Specifically, it has been concluded that the series CH4, GDP, GDP2 and ELC are I(1). As mentioned before, the ARDL approach allows estimation of cointegrating vector with both I(1) and I(0). Regressors of I(0) or I(1) are confirmed by employing ARDL bounds testing to estimate the long-run relationship.

Table 2 Unit root test results

Variable	*ADF test statistic*		*PP test statistic*	
	Intercept	*Trend and intercept*	*Intercept*	*Trend and intercept*
At level				
$\ln CH_{4t}$	–2.313964	–1.636312	–2.534034	–1.768159
$\ln GDP_t$	–0.635519	–1.686456	–0.228806	–1.322664
$\ln GDP^2_t$	–0.590967	–1.649276	–0.171371	–1.280024
$\ln ELC_t$	–0.062128	–2.064094	0.091590	–2.128044
$\ln AGR_t$	–2.021242	–2.973058	–2.065836	–2.953155
At first difference				
$\Delta\ln CH_{4t}$	–5.0337933***	–5.395238***	–4.992671***	–5.395238***
$\Delta\ln GDP_t$	–4.964981***	–5.122566***	–4.897524***	–5.001356***
$\Delta\ln GDP^2_t$	–4.945345***	–5.112700***	–4.879137***	–4.980087***
$\Delta\ln ELC_t$	–6.082031***	–6.035401***	–6.289426***	–6.441275***
$\Delta\ln AGR_t$	–6.524021***	–6.468237***	–6.836457***	–6.935127***

Notes: *** is 1% of significant levels, respectively. The optimal lag length was selected automatically using the Schwarz information criteria for ADF test and the bandwidth is selected using the Newey – West method for PP test.

ARDL approach is based on the number of regressions $(P + 1)^k$ where P is the number of maximum lags and *K* is responsible to show number of variables in each equation. It is the appropriate lag selection procedure that is based on Akaike information criterion, Schwarz information criterion and Hannan-Quinn information criterion. The F-statistic is very sensitive to number of lags in ARDL, because of that, it is necessary for the estimation of F-statistic to choose appropriate lags that are the optimal lag length (Pesaran and Shin, 1998). Our lag selection is based on AIC according with Lütkepohl (2006) pointed that AIC is superior for small sample. The results show that optimal lag length is (1, 2, 2, 0) as is shown in Table 3 for model 1 and in Table 4 for model 2 (optimal lag length is 2, 2, 2, 2).

Table 3 Lag length selection criteria for model 1 cointegration

Dependent variable: $lnCH_4$				
Lag combination	*Log L*	*AIC*	*SC*	*HQ*
(1, 2, 2, 0)	106.263598	–4.863180*	–4.483182	–4.725785
(2, 0, 0, 1)	104.198185	–4.859909	–4.564355	–4.753046
(1, 2, 2, 1)	107.161858	–4.858093	–4.435873	–4.705432
(1, 0, 0, 1)	103.062015	–4.853101	–4.599769	–4.761504
(2, 0, 1, 1)	104.671804	–4.833590	–4.495814	–4.711461

Notes: AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan–Quinn information criterion.
*Indicates lag order selected by the criterion.

Table 4 Lag length selection criteria for model 2 cointegration

Dependent variable: $lnCH_4$				
Lag combination	*Log L*	*AIC*	*SC*	*HQ*
(2.2.2.2)	101.1162	–4.672626	–4.085603*	–4.519582
(2.0.1.0)	95.63320	–4.545297	–4.256634	–4.438167
(2.0.0.2)	100.0337	–4.719679	–4.344973	–4.597244
(2.0.0.1)	98.68008	–4.701543	–4.403260	–4.594412
(2.0.0.0)	93.59336	–4.491967	–4.345665	–4.400141

Notes: AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan–Quinn information criterion.
*Indicates lag order selected by the criterion.

The estimating ARDL (1, 2, 2, 0) model 1 results are shown in Table 5 and ARDL (2, 2, 2, 2) model 2 results are shown in Table 6. We utilise critical bounds developed by Narayan (2005) for small samples because he considered that critical bounds provided by Pesaran and Shin (1998) are biased downward, and may produce misleading results. After the optimal lag structure was selected, the value of the F-statistic is calculated by taking into account the null hypothesis where the parameters estimated with respect to the variables at the level equal to zero (Pesaran et al., 2001). If the calculated value of the F-stat surpasses the critical values of the bounds test, then the null hypothesis of no cointegration is rejected and there is a cointegration relationship between the variables of interest (Bouznit and Pablo-Romero, 2016).

Table 5 Results of the bound test cointegration for CH_4 model 1

Estimated equation	$CH_4 = f(GDP, GDP^2, ELC)$	
Optimal lag structure	*(1,2,2,0)*	
F-statistics	4.026297	
Critical bound values for F-stat	Lower I (0)	Upper I (1)
10%	2.37	3.20
5%	2.79	3.67
2.5%	3.15	4.08
1%	3.65	4.66

Notes: The 5% level of significance is the checking criteria for study using (Pesaran et al.,, 2001) critical values with trend and intercept.

Table 6 Results of the bound test cointegration for CH4 model 2

Estimated equation	$CH_4 = f(GDP, GDP^2, AGR)$	
Optimal lag structure	*(2, 2, 2, 2)*	
F-statistics	3.532992	
Critical bound values for F-stat	Lower I (0)	Upper I (1)
10%	2.37	3.20
5%	2.79	3.67
2.5%	3.15	4.08
1%	3.65	4.66

Notes: The 5% level of significance is the checking criteria for study using (Pesaran et al., 2001) critical values with trend and intercept.

Lagrange multiplier test for serial correlation, Ramsey's RESET test for functional form, in addition to the normality tests and the test for heteroscedasticity were performed reflecting optimal outcomes. Results show that with CH_4 emissions as the dependent variable, the computed F-statistic exceeds the upper bound of 5%. Accordingly, we reject the null hypothesis of no cointegration among the variables, and conclude that there is a long run relationship among CH_4 emissions and its determinants.

The long-run estimation results are shown in Tables 7 and 8. All coefficients are significant and they all have the expected signs. The fact that the coefficient of the variable GDP is positive and the coefficient of the variable GDP^2 is negative, means that the EKC hypothesis is valid for Argentina. From the estimated long-run regression equation, peak point was calculated to be $\beta_1/(2\ \beta_2)$ = 6,993.66 US Dollars in model 1 and 4,150.57 US Dollars in model 2. This value is higher than the highest value of GDP in our sample which can be seen in Figure 1 (the maximum value of the variable GDP is closer to 1,2000.00 in the sample). This result may explain the relationship which was depicted in Figure 1. Moreover, this result is consistent with the study for China by Jalil and Mahmud (2009) which has found EKC's turning point outside of the sample period and another study for Malaysia by Sulaiman et al. (2013) which has found EKC's turning point outside of the observed sample period as well.

Table 7 Long-run estimates based on the selected ARDL model 1

Dependent variable: lnCH₄			
Variable	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	12.32819	3.501450	3.520882***
$lnGDP^2_t$	–0.696287	0.193368	–3.600830***
$lnELC_t$	0.125705	0.023746	5.293611***
Constant	–43.98567	15.88758	–2.768557***
Diagnostic tests			
R^2		0.517348	
Akaike info criterion		-3.715905	
Schwarz criterion		-3.550409	
Breusch-Godfrey serial correlation LM test		16.80255	
Functional form Ramsey rest test		2.265930	
Jarque-Bera normality test		0.556486	
Heteroscedasticity test ARCH		0.341610	
CUSUM		Stable	
CUSUMQ		Stable	

Note: *** represent 1% level of significance.

Table 8 Long-run estimates based on the selected ARDL model 2

Dependent variable: $lnCH_4$			
Variable	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	4.5249	1.5425	2.933441***
$lnGDP^2_t$	–0.27157	0.089593	–3.03114***
$lnAGR_t$	–0.058341	0.015759	–3.702024***
Constant	–7.2360	6.6444	–1.089042***
Diagnostic tests			
R^2	0.816254		
Akaike info criterion		–4.6340	
Schwarz criterion		–4.4272	
Breusch-Godfrey serial correlation LM test		1.2463	
Functional form Ramsey rest test		0.4262	
Jarque-Bera normality test		1.2463	
Heteroscedasticity test ARCH		0.0846	
CUSUM		Stable	
CUSUMQ		Stable	

Note: *** represent 1% level of significance.

Figure 1 Time series plots for CH_4 emissions, GDP, electricity consumption and agriculture value added from 1971 to 2012 (see online version for colours)

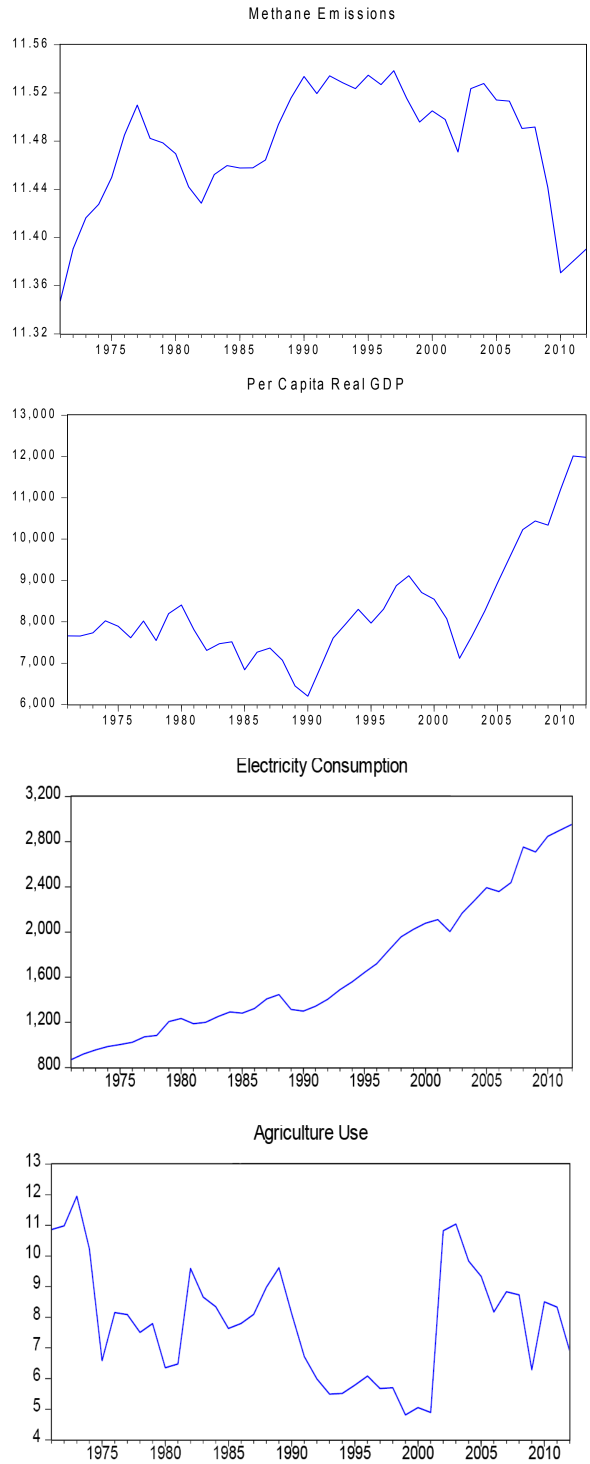

Figure 2 Plots of CUSUM and CUSUMQ for the estimated ECM model 1 (see online version for colours)

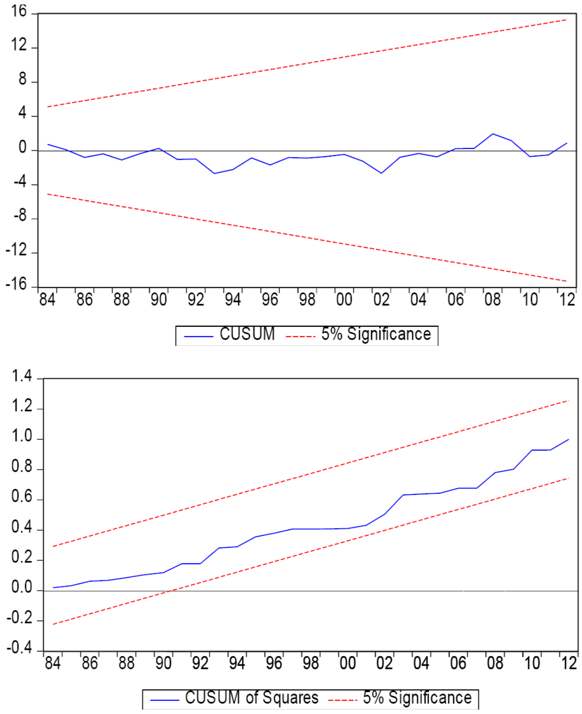

Table 9 Error correction representation for the selected ARDL model 1 (1, 2, 2, 0)

Dependent variable: $lnCH_4$			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$\Delta lnGDP_t$	6.998241	4.889655	1.431234
$\Delta lnGDP^2_t$	–0.390821	0.272152	–1.436038
$\Delta lnELC_t$	0.136603	0.120320	1.135330
ECM(–1)	–0.287776	0.132642	–2.169571**
Constant	–0.001591	0.004996	–0.318434
Diagnostic tests			
R^2		0.374525	
Akaike info criterion		–4.676007	
Schwarz criterion		–4.249453	
Breusch-Godfrey serial correlation LM test		1.028575	
Functional form Ramsey rest test		0.727479	
Jarque-Bera normality test		0.792995	
Heteroscedasticity test ARCH		0.138161	
CUSUM		Stable	
CUSUMQ		Stable	

Note: ** represent 5% level of significance.

Table 10 Error correction representation for the selected ARDL model 2 (2, 2, 2, 2)

Dependent variable: $lnCH_4$			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$\Delta lnGDP_t$	0.001519	0.003091	0.49142
ΔlnGDP2t	1.285262	3.390862	0.379037
ΔlnAGRt	–0.072553	0.199407	–0.363845
ECM(-1)	–0.026913	0.017582	–1.530678**
Constant	–0.281883	0.085189	–3.308902***
Diagnostic tests			
R2		0.491924	
Akaike info criterion		–4.988632	
Schwarz criterion		–4.696071	
Breusch-Godfrey serial correlation LM test		0.4643	
Functional form Ramsey rest test		0.5945	
Jarque-Bera normality test		0.3433	
Heteroscedasticity test ARCH		0.0222	
CUSUM		Stable	
CUSUMQ		Stable	

Note: ** and *** represent 5% and 1% level of significance respectively.

The short-run estimation results are shown in Tables 9 and 10. The coefficient of the error correction term is negative and significant as expected. Coefficients for the GDP differences and the squared GDP have the expected signs. That is, there is evidence of the existence of a short run EKC. The coefficient indicates the adjustment speed to restore the equilibrium in the dynamic model, that is, the effect of a shock will be corrected by 28.78% within a year in model 1 and 2.69% in model 2. Also, Lagrange multiplier test for serial correlation, Ramsey's RESET test for functional form, normality tests and the test for heteroscedasticity were performed reflecting optimal outcomes

The presence of cointegration also implies that causality relations may exist between the variables. In order to find this, it is necessary to specify a reduced form VAR model and to test the significance of the lagged variables in each equation (Saboori and Sulaiman, 2013; Zambrano-Monserrate and Fernandez, 2017; Rosado, 2017; Rosado and Sánchez, 2017). The Granger causality test in a VECM was applied and the results are shown in Tables 11 and 12. The coefficient of ECT_{t-1} is significant, with a negative sign in all equations in Model 1. This indicates that there is bi-causality among all the variables in the long-run. However, there are no causality among the variables in the short-run. Table 12 shows that there is a long-term bi-causality between CH_4 emissions and Agriculture Use, which is an expected factor because CH_4 emissions are caused by livestock activity which we have involved in this study with the use of variable AGR.

Figure 3 Plots of CUSUM and CUSUMQ for the estimated ECM model 2 (see online version for colours)

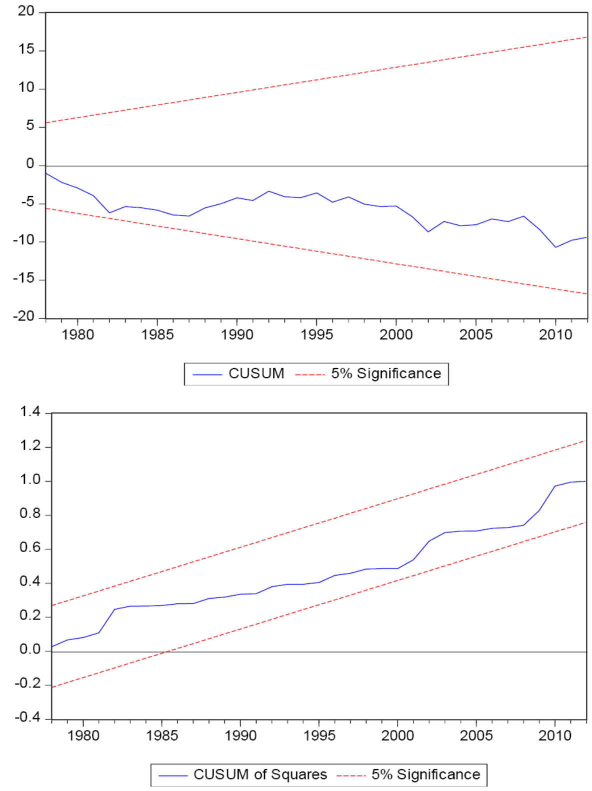

Table 11 Granger causality test model 1 results

Dependent variable	*Short run Sources of causation (independent variable)*				*Long run*
	ΔlnCH$_4$	*ΔlnGDP*	*ΔlnGDP^2*	*ΔlnELC*	*ECT_{t-1}*
ΔlnCH$_4$	-	2.022794 (0.1641)	2.044518 (0.1619)	0.197522 (0.6595)	–0.160651* [–3.170305]
ΔlnGDP	3.134537*** (0.0856)	-	0.486535 (0.4902)	0.079124 (0.7802)	–0.232003*** [–1.758997]
ΔlnGDP^2	3.227659*** (0.0813)	0.445057 (0.5092)	-	0.090647 (0.7652)	–4.122379*** [–1.749646]
ΔlnELC	1.143896 (0.2924)	0.432491 (0.5152)	0.409255 (0.5266)	-	–0.007687* [2.896974]

Notes: Short-run causality is determined by statistical significance of the partial F-statistics associated with the right hand side variables. Long-run causality is revelled by the statistical significance of the respective error correction terms using a t-test. P-values are listed in parentheses and t-statistics are presented in brackets. *Statistical significance at the 1%. **Statistical significance at the 5%. ***Statistical significance at the 10%.

Table 12 Granger causality test model 2 results

Dependent variable	Short run sources of causation (independent variable)				Long run
	ΔlnCH₄	*ΔlnGDP*	*ΔlnGDP²*	*ΔlnAGR*	*ECT*$_{t-1}$
$\Delta lnCH_4$	-	0.17333 (0.9134)	0.184357 (0.9060)	4.811137*** (0.0092)	–0.363023** [-3.170305]
ΔlnGDP	1.987667 (0.1427)	-	0.071837 (0.9745)	0.381626 (0.7671)	0.994134** [2.138228]
$\Delta lnGDP^2$	1.758075 (0.1821)	0.672397 (0.5773)	-	0.383874 (0.7656)	17.76468** [2.132643]
ΔlnAGR	2.572614* (0.20777)	3.831531** (0.0225)	3.219750 (0.406)	-	–0.007687* [2.896974]

Notes: Short-run causality is determined by statistical significance of the partial F-statistics associated with the right hand side variables. Long-run causality is revelled by the statistical significance of the respective error correction terms using a t-test. P-values are listed in parentheses and t-statistics are presented in brackets. *Statistical significance at the 1%. **Statistical significance at the 5%. ***Statistical significance at the 10%.

Table 13 Model 1 results of the fully modified OLS

Dependent variable: lnCH₄			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	11.28578	4.294768	2.627798**
$lnGDP^2_t$	–0.639090	0.237197	–2.694345**
$lnELC_t$	0.118428	0.030593	3.871086***
Constant	–39.18431	19.48751	–2.010738**

Note: ** and *** represent 5% and 1% level of significance respectively.

Table 14 Model 2 results of the fully modified OLS

Dependent variable: lnCH₄			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	15.43039	2.526576	6.107236***
$lnGDP^2_t$	-0.8555209	0.139104	–6.147971***
$lnAGR_t$	0.004890	0.002322	2.105911**
Constant	-58.15181	11.47444	–5.067945***

Note: ** and *** represent 5% and 1% level of significance respectively.

Table 15 Model 1 results of the dynamic OLS

Dependent variable: lnCH₄			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	15.34397	4.875444	3.147195***
$lnGDP^2_t$	–0.868080	0.268198	–3.236719***
$lnELC_t$	0.110477	0.025304	4.366024***
Constant	–57.10249	22.12974	–2.580351**

Note: ** and *** represent 5% and 1% level of significance respectively.

Table 16 Model 2 results of the dynamic OLS

Dependent variable: $lnCH_4$			
Variables	*Coefficients*	*Std. error*	*T-statistics*
$lnGDP_t$	13.46935	5.040743	2.672097**
$lnGDP^2_t$	–0.760878	0.280047	–2.716967**
$lnAGR_t$	–0.017690	0.004122	–4.291792***
Constant	–47.97246	22.69196	–2.114073**

Note: ** and *** represent 5% and 1% level of significance respectively.

The robustness for the coefficients in the long run can be achieved from fully modified OLS (Phillips, 1995) and dynamic OLS (Stock and Watson, 1993). Kao and Chiang (2001) pointed that DOLS outperform than FMOLS. So, we use both tests to confirm the robustness of our long run coefficients from ARDL. The beauty of the DOLS and FMOLS estimators is that they are free from endogeneity issue, small sample size bias and serial correlation (Phillips, 1995; Stock and Watson, 1993). Tables 13 and 14 show that the results from FMOLS and Tables 15 and 16 show the results from DOLS, these results are consistent with the ARDL results in the term of sign and significance that confirm the perfectness of model. So, our sensitivity analysis based on two approaches confirms that our initial ARDL model is robust to statistical biases.

5 Discussion and policy implications

Economic growth and the environment are two distinct phenomena, but their relationship in both the short run and long run is undeniable (Alam et al., 2016). Few studies have analysed CH_4 emissions as an indicator of pollution (Benavides et al., 2017), despite the importance of this GHG at the global level (United States Environmental Protection Agency, 2017). CH_4 emissions occur mainly from agricultural production, which significantly contributes to the economic activity of Argentine, also the electricity sector contributes to economic growth. Thus, there is the need to explore the joint behaviour between economic growth and emissions in order to establish energy and agricultural policies that guarantee a balance between economic growth and environmental prosperity.

The EKC suggests that economic development initially leads to deterioration in the environment, but after a certain level of economic growth, a society begins to improve its relationship with the environment and levels of environmental degradation reduces. The objective of this paper was to empirically examine the short-run and long-run relationship between CH_4 emissions, gross domestic product, electricity power consumption and agriculture use in Argentine for the period of 1971-2012 in our two models. The ARDL approach proposed by Pesaran et al. (2001) was chosen to analyse the relationship among the variables mention before. The significant positive and negative coefficients of GDP and GDP^2 respectively, suggest an inverted U-shaped relationship between per capita CH_4 emissions and per capita gross domestic product supporting the so-called EKC hypothesis in both long and short run. This confirms that CH_4 emissions increase with gross domestic product increase then starts to decline with higher level of economic growth. Estimations from a long-run regression equation, the turning point has been calculated to be $\beta_1/(2\ \beta_2)$ = 5,572.29 US Dollars in average given the coefficients of our models. This turning point, however has been inside of the observed sample period. This implies that CH_4 emissions might start to decrease with the increase in per capita GDP in coming years in Argentina.

The coefficient of CH_4 emissions per capita with respect to electricity power consumption is negative and statistically significant in the long run. Although this effect is positive and statistically significant in the short run, it becomes negative around year 1 since because the ECM term is 0.28 and 0.029. In other words, electricity power consumption and agriculture land use will contribute to environmental enhancement with a one-year lag. Moreover, when electricity power consumption and agriculture use were analysed in this model, a statistically significant relationship between CH_4 emissions could be obtained. This also has very important policy implications for energy and environmental aspects of the country. Methane emissions in abundance in a highly cattle-producing country such as Argentina can be an explanation for our results, in addition, the influence of verified electric energy consumption with an extensive literature as a factor that contributes to economic growth.

The type of relationship that the variables used in this study have is established with the verification of the EKC, that is, in Argentina between the years 1971–2012 there is an EKC which indicates that, in the course of the mentioned years, the economic growth in Argentina has caused considerable wear and tear on natural resources due to the specific margins of ELC and the growth of agricultural activity, however, the current efficiency in the use of environmental resources has caused the means by which growth occurs economic growth does not cause the continued increase of methane emissions, but that economic growth helps sustainable development.

Our results imply the importance of renewable energies in controlling CH_4 emissions in Argentina. A shift in the energy mix towards less polluting energies would be very important in order to achieve environmental targets as well as the sustainable development of the country. Our findings also highlight that regulations to support renewable sources would yield reduction in per capita emissions. Increasing the utilisation of electricity produced from renewable sources will help to mitigate energy dependency and ensure the energy security issue. Therefore, it is envisaged and concluded that these results and the findings of our research ensure highly important information for policy makers in Argentine.

6 Limitations and future research

The EKC hypothesis, which is solely based on the perspective of economics, analyses the relationship between environment pollution load and economic development. Apart from this, the challenge is to synchronise economic development in order to minimise impacts on the environment that is a concern related to the assumptions of sustainability (Maria De Souza Campos et al., 2015). However, it represents an important measure to know the environmental performance of a country with certain assumptions.

In our perspective, a flaw in the EKC is that it assumes all pollutants will behave in generally the same way in relation to income. However, empirical studies have revealed that this is not the case. Whilst certain pollutants such as sulphur or nitrogen oxides have decreased as income has increased, others such as carbon dioxide emissions and solid waste have increased (Stern et al., 1996). Therefore, it can be plausible that the EKC cannot be validated in Argentina with the use of other polluting gases as a dependent variable, a fact that represents an obstacle to this investigation but motivates that this question be covered by future researchers.

It should also be considered that the environmental behaviour in the different regions of Argentina is obviously different, therefore besides national level, there is immense need of formulating regional policies to curb the GHG emissions. A good example is the approach used by Serrano et al. (2015) that examines the economic relationship between income inequality and environmental degradation with panel data in the Brazilian states using the ordinary least squares – OLS, considering the fuzzy set theory. Because the estimate for each state can give a general perspective of the regions to which control and possible government assistance should be directed.

The research challenge now is to revisit some of the issues addressed earlier in the EKC literature using the new decomposition models and rigorous panel data and time series statistics.

The fact that the EKC is validated in this document does not mean that there cannot be another specification later that models the relationship between economic growth and methane emissions, so the validation of different specifications can be a challenge for future research, as well as they can motivate different decisions in the scope of the Argentine economy.

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Notes

1 From this point on, it should be understood that model 2 and the set of functions of the ARDL approach have the same design as the case of model 1 with the exchange of the ELC variable by the variable AGR.