Energy Policy 67 (2014) 923–931

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

System dynamics modelling and the environmental Kuznets curve in Ecuador (1980–2025)

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AUTHOR-HIGHLIGHTS

- We model the CO_2 emissions in Ecuador for the next decade under several scenarios.
- We study the environmental Kuznets curve in the medium term in Ecuador.
- We show that Ecuador will enter into stage 2 of the environmental Kuznets curve in the near future.

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form
29 October 2013
Accepted 4 December 2013
Available online 3 January 2014

Keywords:
CO_2 emissions
System dynamics
Environmental Kuznets curve
Ecuador

ABSTRACT

Is it possible for a country in the process of development to comply with the environmental Kuznets curve (EKC) hypothesis in the medium term? This is the question that inspired this study. This paper is an extension of a previous study focused on economic development and CO_2 emissions in the coming years in Ecuador (Robalino-López et al., submitted for publication). The main goal of this paper is to analyze whether the EKC hypothesis holds within the period 1980–2025 under four different scenarios. This paper uses co-integration techniques (Stock and Watson, 2010) to test the existence of the EKC hypothesis in Ecuador in the medium term using Jaunky's (2011) specification. Our proposal goes a step further than previous contributions, and intends to see under which conditions a country could approach the fulfilment of this hypothesis in the medium term. Results do not support the fulfilment of the EKC, nevertheless, our estimations show that Ecuador could be on the way to achieving environmental stabilization in the near future if economic growth is combined with an increase in the use of renewable energies, an improvement of the productive sectoral structure, and the use of a more efficient fossil fuel technology.

1. Introduction

Ecuador has a relatively low level of CO_2 emissions (2.1 metric tons per capita) while Quatar, the world's largest CO_2 emitter per capita in 2009, emitted 44 metric tons per capita. At the same time Venezuela, the largest CO_2 emitter of Latin America, emitted 6.5 metric tons per capita (World Bank, 2013). It is expected that the social and economic development in the coming years will significantly increase the Ecuador's emissions. Several international organizations, notably, the Intergovernmental Panel on Climate Change (IPCC), are warning about the need to stabilize CO_2 and other anthropogenic greenhouse gas (GHG) emissions in order to avoid a catastrophic warming of the climatic system during this century (IPCC, 2007). To estimate GHG emissions, the IPCC has developed several methods, such as the *Reference Method* (IPCC, 2006), which is a top-down technique that uses data from the country's energy supply to calculate CO_2 emissions, mainly from the burning of fossil fuels. It is a straightforward method that can be applied on the basis of the available energy supply statistics (IPCC, 2006). However, the problem arises when data is not available or is not sufficiently disaggregated for use with this method.

A general question that arises when studying the relationship between the Gross Domestic Product (GDP) and the CO_2 emissions is whether this relationship will be always linear, *i.e.*, that a growth in GDP will produce an increase of the CO_2 emissions (that assumption is somehow implicit in the Kaya identity, Kaya and

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http://dx.doi.org/10.1016/j.enpol.2013.12.003

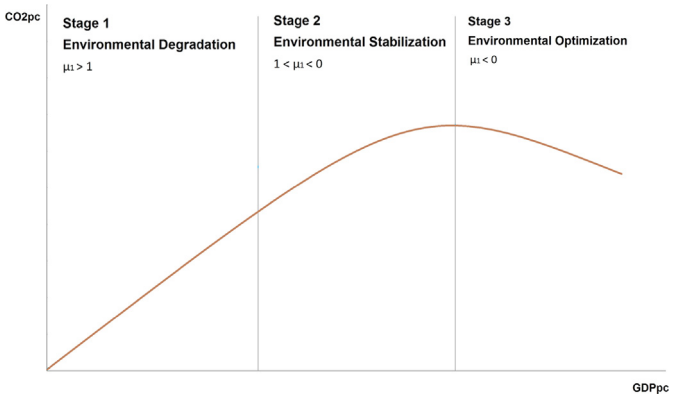

Fig. 1. Schematic plot of the relationship between the GDP per capita (pc) and the CO_2 emission per capita: (1) linear growth of the emission, (2) stabilization, and (3) reduction of the CO_2 emission as the income increases. Figure adapted from Iglesias et al. (2013).

Yokobori, 1993). In the early 1990s it was suggested, almost simultaneously, in Shafik and Bandyopadhyay (1992), Panayotou (1993), and Grossman and Krueger (1995) that this behaviour can be modified and they proposed an "inverted-*U*" shape for the relationship between the GDP per capita and the CO_2 emissions per capita (see Fig. 1). They coined the term Environmental Kuznets Curve (EKC) in analogy to the inverted *U*-shaped relationship between the level of economic development and the degree of income inequality posit by Kuznets (1955).[1] According to the EKC hypothesis the relationship between income per capita and some types of pollution is approximately an inverted *U*. This behaviour states that as the GDP per capita grows, environmental damage increases, reaches a maximum, and then declines. The reason for this behaviour is that when GDP reaches a certain threshold the economy moves into a different regime, where the rate of emissions with respect to income can be reduced with respect to the initial regime. In the initial stage, as in the developing countries, CO_2 emissions scale with the *size of the economy* because the industries are relatively rudimentary, unproductive, and polluting. In the second stage, the impact of the economy in environmental degradation is reduced through the *structure and composition effect*, because the economy growth induces structural changes. In particular, that happens as an agricultural based economy shifts into a manufacturing services based economy. Finally, the third stage appears when *nations invest intensively in research and development and the dirty and obsolete technologies are replaced by clean ones*. At this point the pollution starts to decrease as a function of the GDP. The different phases of the EKC are depicted schematically in Fig. 1.

The inverted *U* shaped relationship between CO_2 emissions and GDP is an empirical observation. In this respect there are many studies where quadratic and cubic models are used to fit the emissions to income (Canas et al., 2003; Shen and Hashimoto, 2004; Cole, 2005; Galeotti et al., 2006; Esteve and Tamarit, 2012a). However, in many cases the evidences of the EKC hypothesis are weak. Another way to test the validity of the EKC assumption is to compare the long and the short run impact of income on emissions (Narayan and Narayan, 2010; Jaunky, 2011). Whatever approach is used or set of countries studied, analysis always uses past data and there are no studies where the EKC hypothesis has been tested in a forthcoming period. To do this, a detailed model of the connection between GDP and CO_2 emissions is needed, as well as a set of plausible scenarios that could describe a possible evolution (GDP, energy matrix, and sectoral structure) of a given country.

As the theory predicts a long-run relationship linking emissions and economic growth, there is a wide stream of recent research that has assessed this relationship employing co-integration techniques. The empirical evidence suggests that pollution levels and GDP may be jointly determined, so that any constraint put on energy consumption, to help in reducing emissions, will have effects on economic growth. Some authors (Soytas et al., 2001; Soytas and Sari, 2001; Lee, 2005; Lise, 2006; Chontanawat et al., 2008; Halicioglu, 2009; Ozturk and Acaravci, 2010; Esteve and Tamarit, 2012a,b; Fosten et al., 2012 among others) use cointegration procedures to examine the CO_2 and GDP nexus, however these studies analyze past evidence. Our proposal goes a step further and intends to see under what conditions a country could approach the fulfilment of the EKC hypothesis in the medium term.

To this end, we will use a model recently proposed by Robalino-López et al. (submitted for publication), extending it for the period 1980–2025. The model is based on a variation of the Kaya identity (Kaya and Yokobori, 1993), and on a GDP formation approach which includes a contribution from renewable energy (Chien and Hu, 2008). The model has been implemented using the system dynamics technique (Forrester, 1961) on a Vensim platform (Vensim, 2011). System dynamics is a method for modelling, simulating and analyzing complex systems and its main goal is to understand how a given system evolves (Radzicki and Tauheed, 2009; Tan et al., 2010; García, 2011). To fix the unknown parameters of the model we have considered data from 1980 to 2010 which was extracted from the official data set of Ecuador.[2] Once the parameters of the model were fixed, four different scenarios were defined and this allowed us to perform the prediction of CO_2 emissions in a medium term period.

The present study is an effort to fill the gap in the literature of studies on the relationship between emissions and GDP in Latin American countries in general, and in Ecuador in particular. In addition, studies of a single country help policy makers improve comprehensive policies to control environmental degradation. Moreover, it represents a step forward in the study of the EKC hypothesis following Jaunky's specification (Jaunky, 2011), due to the inclusion of a forthcoming (2011–2025) and not just a past period of time. In Jaunky (2011) the author tries to test the ECK hypothesis in a set of high-income countries for the period 1980–2005. The lower long-run income elasticity does not provide evidence for the EKC, but it indicates that CO_2 emissions are stabilizing in rich countries. Therefore, the extension of this work to other countries and to a forthcoming period is of interest.

The paper is organized as follows: Section 2 summarizes the main data indexes of Ecuador and outlines the method used for the case study; Section 3 presents and discusses the main results of this paper and lastly, Section 4 provides the summary, conclusions and policy implication.

2. Study area and methodology

2.1. Overview of the study area

Ecuador is a medium-income country with a Human Development Index score of 0.724 (UNDP – United Nations Development

[1] For an exhaustive survey see Stern (2004) and Dinda (2004), or more recently Pasten and Figueroa (2012).

[2] Data is from the Ecuadorian Institute of Statistics and Census (INEC, 2012), Central Bank of Ecuador (BCE – Banco Central de Ecuador, 2012), World Bank (2013), and International Energy Agency (IEA) (2013). Economic official data set used is given in constant 2005 PPP (purchasing power parity) international dollars (World Bank, 2013). In the rest of this paper GDP-PPP will be referred to only as GDP, for brevity.