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Carbon footprint and emission determinants in Africa

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ABSTRACT

Increasing economic activities and rapid demographic changes in a number of African countries may have consequential effects on environmental quality. In this paper, a multi-region input–output modeling framework is used to show that except Egypt, Nigeria, Tunisia, South Africa, Zimbabwe and the Rest of North Africa, all other African countries/regions are net-importers of embodied emissions. With respect to the emission-intensive and trade exposed sectors, however, only Egypt, Mozambique, South Africa and Zimbabwe are rather net-exporters of embodied emissions. Secondly, panel regression techniques that allow cross-section dependence are used to investigate the determinants of CO_2 emissions in Africa. The estimated elasticities for per capita income and energy intensity are positive, statistically significant and robust for both low- and middle-income African countries. The most active segment of the labor force (percentage of the population between age 14 and 64) and industrialization exert significant positive effects on CO_2 emissions in middle income countries while the impact of urbanization, population and trade openness appears generally insignificant across income groups. The differential impacts of both economic and demographic variables on CO_2 emissions may have implications for the design and implementation of development and climate protection policies.

1. Introduction

The process of economic development in Africa is associated with a shift from traditional agricultural-based economies to agricultural intensification, industrialization, value addition, expansion of the service sector and changes in consumption patterns. Against the backdrop of the EKC (Environmental Kuznets Curve) hypothesis and the fact that production and consumption activities are largely reliant on energy consumption, the pursuit for rapid economic growth in Africa may have wide-ranging implications on energy use and emissions. In other words, Africa is generally at the initial stage of the EKC where economic growth leads to increased energy demand and emissions [1].

Although the empirics regarding economic development, energy use and CO_2 emissions have so far been mixed, empirical evidence with reference to African countries suggest a causal relationship. For example, recent studies suggest that energy consumption drives economic development in a number of African countries [2,3]. Similarly, Mensah [4] finds increasing energy use as a driver of CO_2 emissions in Ghana and Nigeria while in Nigeria, Senegal and Egypt the author observes unidirectional causality from economic growth to CO_2 emissions.

Other studies [5–10] find similar results with the overall conclusion suggesting a long-run unidirectional and/or bidirectional causality between energy use and economic development. These findings have direct implications for African economies. First, limited access or constrains to the provision of energy could impact negatively on economic development. Second, value additions in these economies are energy or carbon-intensive and in the absence of cleaner alternative energy sources or energy-saving technologies, a reduction in CO_2 emissions could only be achieved by sacrificing energy use and economic growth.

Besides economic growth, significant changes in demographic trends such as urbanization and population have also been observed in Africa [11,12]. For example, increased urban growth (about 3.5% per annum) has been observed over the last two decades and more than half of Africa's increasing population is expected to reside in urban cities by 2040 [12,13]. Urbanization is a key feature of economic growth and both trigger structural changes with consequential effects on energy consumption [14] and the environment. For example, the urban environmental transition theory asserts a higher urbanization effect on energy use and CO_2 emissions as income increases. This occurs as a result of increased demand for resource intensive goods and public infrastructure –

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leading to an increase in per capita resource consumption and emissions [15].

The ecological modernization hypothesis on the other hand, suggests efficiency in the use of energy or resources that occurs as a result of structural changes e.g., a shift towards service-based industries and technological innovation which tend to lessen the effect of economic development on emissions [16,17]. The compact city theory also argues in terms of efficiency improvement in the use of resources due to urban compaction [18–20]. The exodus of the labor force from rural areas into urban areas in pursuit of better standard of living not only results in densely populated urban cities, but it also leads to the concentration of economic activities in urban areas. This phenomenon drives economies of scale in production and provision of public infrastructure and hence reduces energy losses due to transmission and distribution, decreases energy consumption and CO_2 emissions.

Aside these theories, empirical evidences also suggest that urbanization tends to increase energy consumption and CO_2 emissions [21–26]. Particularly for CO_2 emissions, Poumanyvong and Kaneko [19] find a significant positive urbanization effect for all income groups with the impact being more pronounced in middle income economies. In contrast, Martínez-Zarzoso and Maruotti [27] observe an inverted U-shaped relationship between urban growth and CO_2 emissions, implying that subsequent increases in the rate of urbanization beyond a certain threshold rather mitigate CO_2 emissions. Likewise, Sharma [28] detects an inverse relationship between increasing urbanization and CO_2 emissions, although the negative urbanization coefficients become statistically insignificant when panel units are grouped into low-, middle- and high-income countries. The studies above stress varying impacts of urbanization on emissions in different income classes and the need to factor this in cross-country panel studies.

Aside the impact of economic development and demographic changes on energy-related CO_2 emissions, African countries are also involved in international trade and responsible not only for their own emissions, but emissions in other countries via trade. International trade serves as a conduit between economic activities in different regions and creates a wedge between production-based and consumption-based emissions of a country. Note that the production-based accounting principle captures all CO_2 emissions associated with production activities within a country but ignore a distinction between export and domestic consumption. The consumption-based approach on the other hand, accounts for direct and indirect CO_2 emissions that are related to the use of final goods and services [29] and attributes the emissions responsibility to the region where consumption occurs. As a result, the consumption-based approach captures all CO_2 emissions associated with the production of goods and services used in final consumption irrespective of territorial boundaries.

Empirical studies show that despite the relatively stable levels of CO_2 emissions in developed countries within the last two decades, emissions embodied in international trade has increased substantially [30,31]. Consequently, industrialized nations are largely considered as net-importers while developing economies tend to be net-exporters of emissions [31]. Thus, the increasing economic activities and participation of African countries in international trade may not only affect domestic direct emissions, but emissions embodied in trade due to increasing imports and exports from other nations.

Note that CO_2 externality is global in nature, however, most of the studies on emissions embodied in trade focus more on trends in developed and emerging economies with less attention to developing regions such as the African continent. To fill this gap, this paper uses a MRIO (multi-region input–output) model to quantify the carbon footprint of African countries and the emission-intensity of goods produced in the so called "energy/emission-intensive and trade exposed" (EITE) sectors.[1] The mixed results from the literature on the drivers of CO_2 emissions also call for further enquiry considering the fact that much less is known empirically about the determinants of CO_2 emissions particularly in Africa. This paper uses recently developed panel data techniques that allow cross-section dependence to estimate the economic and demographic determinants of CO_2 emissions in low and middle income African economies.

The remaining sections are outlined as follows. In Section 2, a brief description of the MRIO model and the subsequent results are presented. Section 3 deals with data and the econometric model. Lastly, in Sections 4 and 5, the empirical results and conclusions are presented, respectively.

2. MRIO (multi-region input–output) analysis

2.1. MRIO model

The MRIO analysis relies on the Global Trade Analysis Project (GTAP 8) database which provides consistent production, input–output, consumption, trade and CO_2 emission data for 129 regions and 57 sectors for the year 2007 [32].[2] The MRIO approach keeps track of emissions embodied in both domestic inputs and intermediate imports across countries and sectors. To reflect differences in energy-intensity and trade exposure, the dataset is aggregated into 16 sectors of which the emission-intensive and trade exposed sectors are explicitly included as individual sectors and also as a composite sector. The emphasis on the EITE sector is primarily due to the fact that these sectors are usually at the forefront of policy concerns on competitiveness. Based on the focus of this paper, the regions in the dataset are aggregated into 28 regions: 21 individual African countries in the dataset, 6 regional aggregations which capture all other African countries and a composite region -"Rest of the World" (see Table A1 in the Appendix).

The approach by Refs. [33,34] is followed to compute embodied emissions (in production, consumption, exports and imports) and the composition of the carbon content (defined as the embodied carbon in kg CO_2 per US$ of output) of goods produced in the EITE sectors.[3] The composite embodied emissions in the final output Y produced in sector g in region r also known as production-based emissions entails the total amount of CO_2 which stems from direct emissions (CO_2e_{gr}) from the combustion of fossil fuel inputs i and indirect emissions to produce domestic intermediates (I^D_{igr}) mainly representing electricity inputs and imported (I^M_{igsr}) intermediate inputs from region s. The MRIO identity can therefore be defined as:

$$ec^Y_{gr}Y_{gr} = CO_2e_{gr} + \sum_i ec^Y_{ir}I^D_{igr} + \sum_s \sum_i ec^M_{is}I^M_{igsr} \quad (1)$$

where ec^Y_{gr} represents the carbon content or emission intensity factor of sector g – determined endogenously by solving Equation

[1] In this paper, carbon footprint is defined as only the total CO_2 emissions emitted in the production of goods and services as well as the CO_2 emissions associated with final consumption.

[2] Although the GTAP database is the most comprehensive global input/output database available, the fact that it is obtained from different national statistical offices requires internal manipulations to harmonize and balance the various data sources. This process may introduce some uncertainties in the dataset leading to either over or under-estimation of the production and consumption values. This could affect the accuracy of the embodied emissions computed.

[3] Böhringer et al. [34] provide a detailed model description with application to the GTAP database.