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Carbon (CO_2) emission and food availability convergence in the Niger Basin region: Insight from a club clustering algorithm

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Abstract

The study employed the Phillips and Sul log-t convergence test to analyse the degree of convergence for the Niger Basin region (NBR) countries in terms of per capita carbon emission and food availability. We found that, between the years 1986 and 2020, the Niger Basin region produced 13.5% less food per person than it did during the base period of 2004 to 2006. This study also found a strong convergence among the NBR countries on per capita food production. The result for the region's convergence of per capita carbon emission was rejected. The non-convergence of the entire sample, and the presence of the different subgroup convergence clubs for per capita CO_2 emission for the region, implies that individual factors characterise the NBR countries in terms of per capita CO_2 emissions, which in turn determine an idiosyncratic course of their transition path for per capita CO_2 emission policies. Considering that the transboundary river basin links nine countries, this study recommends that the NBR countries formulate and implement CO_2 emission policies based on club- and country-specific policies to achieve convergence in relation to a concerted food security threat facing the region.

Key words: Niger River basin, convergence club, log-t regression test, per capita carbon emission, per capita food production

1. Introduction

There is a growing consensus that human-generated emissions of greenhouse gases, particularly carbon dioxide (hereafter carbon or CO_2), have an observable influence on the earth's climate (IPCC 2007, 2013). One of the areas being affected is the Niger Basin region, which cuts across Benin Republic, Burkina Faso, Ivory Coast, Guinea, Mali, Niger, Nigeria and Chad in West Africa, and

Cameroun in Central Africa. The Niger Basin is of paramount importance for the West Africa region (African Development Bank Group 2019), as many farmers and herders in the region rely on it for their livelihoods.

However, the region is experiencing the effects of climate change, which is a consequence of increased carbon emissions, which have a negative effect on food availability and food security. As pointed out by the Green Climate Fund (2018), the Niger Basin has been one of Africa's regions that has been most vulnerable to climate change in the last six decades, with annual rainfall reduced by 20% to 40%, resulting in continuous and recurrent droughts. This has strong implications for food availability in the region.

A study by Konate et al. (2019), on the relationship between carbon emissions and food security in the Niger Basin region, found that carbon emissions from agricultural activities in the region have increased over the past decade due to factors such as deforestation and the use of fossil fuels. These emissions have contributed to climate change, which has affected food availability and food security by altering rainfall patterns and increasing the occurrence of droughts and floods. Despite this, evidence showing the convergence of carbon emissions and food availability in the Niger Basin region remains scarce.

Convergence suggests that per-person output levels will become similar across all economies over time. The idea is being investigated in empirical growth studies, with numerous researchers contributing to developing techniques to test for convergence and analyse its validity across different regions and nations. (Baumol 1986; Barro & Sala-i-Martin 1992; Bernard & Durlauf 1995; Barro & Sala-i-Martin 1997; Lee et al. 1997).

In the past few years, convergence analysis has also been employed to examine other subjects, such as the cost of living (Phillips & Sul 2007), eco-efficiency (Camarero et al. 2013a), corporate tax (Regis et al. 2015), military expenditure (Arvanitidis & Kollias 2016; Lau et al. 2016; Güriş et al. 2017; Solarin 2019) and military expenditure and security outcomes (Saba & Ngepah 2019). Saba and Ngepah (2022) analysed convergence in renewable energy sources for 183 countries. Significant contributions have also been made to the convergence of CO_2 emissions across the globe (see Panopoulou & Pantelidis 2009; Strazicich & List 2003; Nguyen Van 2005; Aldy 2006; Jobert et al. 2010; Brock & Taylor 2010; Camarero 2013b).

Despite these contributions, more studies need to be done about the convergence of CO_2 emission and food availability. Although there is an established collection of research on the relationship between carbon emission and food security, as well as the factors that drive food availability – which is a component of food security – very little is understood about the convergence of carbon emissions and food availability in countries clustering the Niger Basin in Sub-Saharan Africa.

This study therefore is a departure from other studies, as it utilises Phillips and Sul's (2007) methodology, which has certain benefits compared to standard statistical methods used in global research, such as beta (β), sigma (σ), and stochastic convergence. The Phillips and Sul approach considers the potential for transitional heterogeneity or divergence, which is significant because it can be challenging to assess convergence using unit root and cointegration tests in the presence of heterogeneity. Phillips and Sul have suggested that convergence can still exist, even if series are not cointegrated. Their technique is an asymptotic cointegration test that avoids the problems associated with unit root and cointegration tests. Furthermore, this analysis is not based on the assumptions of trend stationarity or stochastic non-stationarity. It hypothesises that certain countries, states, sectors or regions that share a common attribute will eventually settle into a steady-state position. This approach has some advantages, such as not requiring any assumptions about the stationarity of the variable of interest or the presence of certain common factors.

In order to ensure that the results of the club convergence test are accurate, Phillips and Sul (2009) further propose running the algorithm across sub-clubs to determine if there is evidence to suggest that clubs should be merged into larger clubs. To further bolster the results of the log-t convergence test, a club-merging algorithm test was proposed to help avoid any overestimation of the convergence club results.

To the best of our knowledge, no prior investigations have analysed the convergence of carbon emissions and food availability using the convergence club method in the Niger Basin region. To fill this research gap, this study aims to investigate the convergence of carbon emissions and food availability in a balanced panel of nine countries in the Niger Basin region of Africa from 1986 to 2020. Overall, past studies have suggested that carbon emissions and food availability have been converging globally and within countries. However, it is essential to note that, while carbon emissions and food availability are increasing in many regions, there are still disparities in these aspects within and between countries.

In this study, the test for club convergence is crucial because it serves two primary purposes. Firstly, convergence clubs help compare and examine a country's development in comparison to that of another country regarding food availability and CO_2 emissions and to identify groups of countries in each region that converge to different equilibria, while allowing individual countries to diverge. Secondly, by identifying similarities or differences between countries in the Niger Basin region, we can draw generalisations or specific conclusions and identify reasons why countries that do not belong to any convergence group in the Niger Basin region have diverged, providing further insights into the factors influencing the similarities or differences in CO_2 emissions and food availability among the countries in the region.

2. Literature review

2.1 Studies on convergence in carbon emissions

The idea of convergence concerning carbon emissions is based on the findings of Bulte et al. (2007). It is accepted that there is a convergence of income per capita among countries and regions, and an inverted U-shaped relationship between income and pollutants, also known as the environmental Kuznets curve (EKC). The Solow model furthermore proposes that pollution is a by-product of consumption, and the EKC captures this idea. The environmental Kuznets curve also suggests that, in the long term, technical change will drive income growth, and emissions will decrease when income reaches a certain threshold. In contrast, in the short term, countries will converge on their own income and emissions paths, meaning that some countries could have increasing emission levels while others have decreasing levels. If the difference in income growth between countries is significant, the overall emission levels will diverge, but if the difference is slight, emissions will converge (Pettersson et al. 2013).

Also, there is substantial empirical evidence on the convergence of carbon dioxide emissions across countries (Strazicich & List 2003; Nguyen Van 2005; Aldy 2006; Panopoulou & Pantelidis 2009; Brock & Taylor 2010; Jobert et al. 2010; Camarero et al. 2013a). In general, the findings from the majority of the research indicate a significant divergence in carbon emissions on a global scale and for low-income nations. At the same time, there is substantial evidence of convergence in per capita carbon emissions among developed countries, namely those belonging to the OECD. The global divergence can be attributed to countries' uneven distribution of fossil fuels, and the transportation costs of these fuels are relatively high (Pettersson et al. 2013).

In the same vein, an early observation of this phenomenon in the environmental economics literature was made by List (1999), who studied sulfur dioxide and nitrogen oxides by following the guidelines developed by Baumol (1986) for determining β-convergence. β-convergence occurs when poorer countries, with initially lower emissions per capita, grow faster than more prosperous countries, resulting in a catching-up effect with the more polluting countries.

Despite evidence that total emissions are rising in many countries, per capita emissions have stabilised globally and in several individual countries. If national data demonstrate a convergence towards similar trends, setting targets based on per capita emissions may be a more feasible approach to political compromise than using absolute emission levels (Ordás Criado & Grether 2011). Developing countries may favour this policy with lower per capita carbon emissions because it would require countries with higher per capita emissions to take more responsibility for reducing emissions, allowing developing countries to continue growing economically while addressing climate change.

2.2 Empirical evidence of the convergence of food availability

Several empirical studies have recognised the importance of food availability across the countries of the world (Regmi et al. 2008; Agboola & Balcilar 2014; Fukase & Martin 2020), although they have paid little attention to the convergence of food availability among countries. Despite the scarcity of empirical literature on the convergence of food availability, especially in a sub-regional context like the Niger Basin, some studies have considered food availability convergence from a global perspective. For example, Bell et al. (2021) reported in their study that food availability has been converging across countries over the last four decades. This might be due to the interdependence among countries, as globalisation has pushed nations to increase cross-border trade, interaction, and the spread of shocks from one country to another (Olaniyi & Odhiambo 2023). Also, in an earlier study, Brunelle et al. (2014) noted that globalisation tends to drive convergence in the food diet, as every region in the world is converging towards the United States.

Furthermore, Fukase and Martin (2020) examined the implications of economic convergence on food supply and demand across the globe. The results indicate that developing countries have been growing faster than developed countries, increasing demand for agricultural resources as food demands shift towards animal-based products, fruits and vegetables. This further increases pressure on food affordability as world food prices increase. In the same vein, Le et al. (2020) recognised the convergence in food supply across the globe, including the existence of unequal access to food that affects subgroups of the population, despite the convergence in food supply. Also, from a regional perspective on food availability convergence in developing countries, particularly on nutrient supply in Sub-Saharan African (SSA) countries, it was reported that low-speed convergence exists among the countries in the SSA region, hence leading to widespread poverty in SSA (Ogundari & Ito 2015).

It is also pertinent to know that several multilateral organisations have explored the idea of the convergence of food availability. For example, a report by the Food and Agriculture Organization (FAO 2018) of the United Nations states that "globalization and technological advances in transportation and communication have contributed to the convergence of food availability across countries". The report also notes that trade has become an increasingly important factor in food availability, with countries importing and exporting food to meet their needs. Another study by the FAO (2019) reported that the per capita food supply in developing countries increased by 17% from 2000 to 2017, while in developed countries it increased by only 1%. This suggests that food availability is converging globally as developing countries catch up with developed countries regarding food supply (FAO 2019).

In analysing the convergence of food availability from a regional perspective, Carr et al. (2016) found that the food availability gap between regions has been narrowing and reducing as international trade and globalisation are making it possible to move food from countries with greater availability to countries with lower ability, and this process is becoming faster. Furthermore, from a country perspective of convergence in food availability, a study by the International Food Policy Research Institute (IFPRI) found that food availability has been converging within countries due to the increased use of trade and markets. The study found that the gap in food availability between urban and rural areas has been narrowing in many countries, due to increased trade and market integration (IFPRI 2012).

Generally, the use of technology and innovation in food production has also been identified as a critical factor in reducing disparities in food availability. For example, a report by the World Economic Forum ([WEF] 2020) states that "advances in agricultural technology have increased the productivity of land and water, which has contributed to a narrowing of the food availability gap". The report highlights technologies such as precision agriculture, vertical farming and genetic engineering as innovations that increase food production and reduce food waste.

Despite these trends toward convergence, there are still significant disparities in food availability between countries and regions. The FAO (2018) notes that "the persistence of food insecurity in many regions is a major challenge to achieving convergence in food availability". Factors such as increased carbon emissions, leading to climate change, can disrupt food production and distribution, causing further disparities in food availability. This study makes a valuable contribution to the limited empirical literature on food availability convergence in the Niger Basin region by utilising Phillips and Sul's (2007, 2009) methodology to examine this phenomenon.

3. Methodology and estimation strategy

3.1 Log-t convergence test

This study utilises the methodology of the log-t convergence test proposed by Phillips and Sul (2007) to examine convergence and convergence clubs for carbon emission and food availability across a panel of nine countries in the Niger Basin region. The specification of the convergence of CO_2 emissions and food availability in the Niger Basin region is therefore based on a modification of the conventional panel data decomposition of the variable of interest, X_{it}, into:

$$Y_{it} = \delta_{it} + \alpha_{it}, \tag{1}$$

where δ_{it} is the systematic factor (which captures the permanent common component) and α_{it} is the transitory component of the equation. To address temporal transitional heterogeneity, equation (1) is modified as follows:

$$Y_{it} = \left(\frac{\delta_{it} + \alpha_{it}}{\mu_t} \mu_t \right) = \beta_{it} \mu_t, \tag{2}$$

where β_{it} is the systematic idiosyncratic element that can evolve over time and include a random component that absorbs α_t, while μ_t is the model's common factor, therefore, β_{it} is the transitory path of the economy to the common steady-state growth path determined by μ_{it}. Remarkably, the typical growth component, μ_{it}, may follow either a trend-stationary process or a non-stationary stochastic trend with drift, since a specific assumption regarding the behaviour of μ_{it} is not necessary.

To test if different countries within the region of study converge, a key role is played by the estimation of β_{it}. Estimating this parameter is impossible without imposing additional structural restrictions and assumptions. However, as a viable way of modelling this element, the construction of the following relative transition component is specified as

$$h_{it} = \frac{Y_{it}}{\frac{1}{N}\sum_{i=1}^{N} Y_{it}} = \frac{\beta_{it}}{\frac{1}{N}\sum_{i=1}^{N} \beta_{it}} \tag{3}$$

Equation (3) is called the relative transition path and can be computed directly from the data. In this manner, it is possible to remove the common steady-state trend, μ_{it}, and tracing an individual trajectory transition path for each economy i about the panel average. In other words, the relative transition path describes the relative individual behaviour and the relative departures of the ith economy from the common growth path, μ_{it}. In the presence of convergence, there should be a standard limit in the transition path of each economy, and the coefficient h_{it} should converge towards unity($h_{it} \rightarrow 1$) for all $i = 1, \ldots, N$, as $t \rightarrow \infty$. At the same time, the cross-sectional variation, h_{it} (computed as the quadratic distance measure for the panel from the standard limit), should converge to zero:

$$H_t = \frac{1}{N}\sum_{i=1}^{N} (h_{it} - 1)^2 \rightarrow 0 \qquad \text{as } t \rightarrow \infty \tag{4}$$

Following Philips and Sul (2007, 2009), the semi-parametric specification for the statistical test for convergence of β_{it} is specified as below:

$$\beta_{it} = \beta_i + \delta_{it}\gamma_{it}, \tag{5}$$

where β_{it} is fixed (not time-variant), γ_{it} is an independent and identically distributed (i.i.d.) $N(0,1)$ random variable over i, but weakly dependent over t. Also, $\delta_{it} = \frac{\delta_i}{L(t)t^{\alpha}}$, with $L(t)$ varying slowly, increasing and diverging at infinity in the function $[L(t) \rightarrow \infty \text{ as } t \rightarrow \infty]$, and α is the convergence rate. The expressions below are the null and alternative hypotheses for testing the convergence:

H_0: $\beta_i = \beta$ and $\alpha \geq 0$ (hypothesis of convergence for all i (countries) in the Niger Basin region)
H_1: $\beta_1 \neq \beta$ for all i, or $\alpha < 0$ (hypothesis of non-convergence for some i (countries) in the Niger Basin region)

It is important to note that, under H_0, different transitional paths are possible, including temporary divergence towards convergence in CO_2 emissions and food availability in the Niger Basin region.

Also, to test for convergence among the different economies in the Niger Basin region on CO_2 emissions and food availability, the study follows the specifications of Philips and Sul (2007, 2009), which suggest the estimation of Equation (6) below through the ordinary least squares method:

$$\log \frac{H_1}{H_t} = -2\log(\log t) = \alpha + \beta \log t + \varepsilon_t , \tag{6}$$

for $t = [rT], [rT] + 1, \dots, T$; where H_t is $\left(1/_N\right) \sum_{i=1}^{N} (h_{it} - 1)^2$, as defined earlier in Equation (4), $H_1/_{H_t}$ is the cross-sectional variance ratio, $-2 \log(\log t)$ is a penalisation function that improves the test performance, β is the speed-of-convergence parameter of β_{it}, r is a positive value in the interval $(0,1)$ to discard the first block of observations from estimation, and [rT] is the integer part of rT. In this regard, Phillips and Sul suggest using $r \in [0.2, 0.3]$ for a small sample size $(T < 50)$ as a result of Monte Carlo simulations. The null hypothesis of convergence is tested through a one-sided t-test robust to heteroskedasticity and autocorrelation (HAC) of the inequality $\alpha > 0$ (using the estimated $\hat{\beta} = 2\alpha$). Specifically, it is rejected at the 5% level if $t_{\hat{\beta}}$ is less than -1.65.

The empirical convergence literature also addresses the potential presence of multiple equilibria. Therefore, if the null hypothesis that all countries in the sample converge is rejected, it does not necessarily indicate the absence of convergence clubs in the panel. This study employed the club convergence and clustering approach developed by Phillips and Sul (2007) to address this issue. The steps involved in this procedure are as follows:

a. The N countries will be arranged based on the final period value of the time series. For instance, in the context of CO_2 emissions, the countries will be ranked in descending order, with the first country having the highest final-period CO_2 emissions, the second with the next highest CO_2 emissions, and so on.
b. All feasible core (club) groups, C_k, will be created by choosing the first k highest-ranked countries, where $k = 1, 2, 3, \dots, N$. Then, they will be assessed for convergence using the log t_k test within each subgroup of size k. Finally, the core club, C^k, of size k^* will be established as the club for which the maximum computed log-t_k^* statistic is observed, provided that the log-t_k statistics affirm the convergence hypothesis.
c. Starting from the remaining $N - k^*$ countries, one country will be added at a time to the core club, C^*, and examined for convergence using the log-t test. If the test provides strong evidence to support the convergence hypothesis ($\log t \geq 0$), then the country can be added to group C^*. All countries that are identified, based on the log-t test, to converge to the same steady state as the core group, C^*, along with the countries of the core group C^*, will establish the first convergence club in the panel.
d. The steps outlined in (a) to (c) will then be repeated for the remaining countries, if any, to identify the next convergence club, if it exists. The procedure ends when the remaining economies do not converge.

3.2 Robustness test (club merging algorithm)

To ensure the accuracy and reliability of our findings on CO_2 emissions and food availability in the Niger Basin region, we used the Phillips and Sul (2009) test of club merging to supplement our analysis. This test is necessary because the convergence club methodology used in the analysis may, according to Phillips and Sul (2009), overestimate the number of clubs. To address this issue, the algorithm was applied to sub-clubs to determine if merging clubs into larger clubs would be appropriate. The algorithm was designed to identify all possible arrangements of cluster algorithms, such as panel convergence, panel divergence, converging subgroups, and individual diverging units. Phillips and Sul (2007) suggest using conservative values for the critical value c in step c, particularly $c = 0$, to minimise the chances of including an incorrect member in a convergence group. However, this approach may result in overestimating the number of convergence clubs. To address this issue, Phillips and Sul (2009) propose conducting convergence testing between clubs and merging them if the null hypothesis is not rejected. In this study, we considered an alternative formulation of the alternative hypothesis, in addition to the one presented in the previous section (viz., $H_A: \beta i \neq \beta, \text{or } \alpha < 0$):

$$H_A : m_{it} \rightarrow \begin{cases} \frac{m_1}{m_2} \end{cases} and \alpha \geq 0 \Rightarrow i \in W_{1,} and \alpha \geq 0 \Rightarrow \in W_2 \tag{7}$$

where the sum of W_1 and W_2 aggregates to N. Hence, this concept can be applied to situations with more than one club. The transition coefficient concerning this is defined as:

$$h_{it} = \frac{m_{it}}{N^{-1}\sum_{i+1}^{N} m_{it}} \rightarrow \begin{cases} \frac{m_1}{\gamma m + (1-\gamma)m_2} \\ \frac{b_2}{\gamma m_1 + (1-\gamma)m_2} i \in W_{1,} i \in W_2 \end{cases} \tag{8}$$

and

$$H_t = N^{-1}\sum_{i=1}^{N}(h_{it} - 1)^2 \rightarrow \frac{\gamma(1-\gamma)\{\gamma m_1^2 + (1-\gamma)m_2^2\}}{\{\gamma m_1 + (1-\gamma)m_2\}^2} \tag{9}$$

After considering all cases where γ is not equal to 0 or 1, and where m_1 is not equal to m_2, we end up with a logarithmic t regression model that can be represented by Equation 6.

Using the method mentioned above, the research examined whether there was convergence, complete divergence or convergence clubs regarding the carbon dioxide (CO_2) emissions and food availability in the Niger Basin region between the years 1986 and 2020.

3.3 Data

In order to investigate whether there is convergence in carbon emissions and food availability in the Niger Basin countries, this study utilised annual data from 1986 to 2020 for a panel consisting of nine countries in this region of Sub-Saharan Africa.[1] Due to data unavailability, particularly for 2021 and 2022, recent years had to be excluded from the analysis.

[1] The countries are Benin, Burkina Faso, Ivory Coast, Guinea, Mali, Niger, Nigeria, Chad and Cameroun.

Table 1: Dataset

Variables	Indicator/descriptions	Sources
Carbon emissions (CO_2)	Per capita CO_2 emissions (measured in metric tons) are provided by the World Development Indicators (World Bank). The data include carbon dioxide emissions from solid, liquid and gas fuels and gas flaring (Panopoulou & Pantelidis 2009).	Ritchie et al. (2020)
Food availability (AVAIL)	Gross per capita food production index. Number (2014 to 2016 = 100). Proxy for food availability. It measures the level of food production per person in a given year relative to the base period of 2014 to 2066, which is assigned a value of 100. It considers both the total food production and the population of a country or region. The index considers factors such as changes in crop yields, planted areas and harvested areas. The commodities included are considered edible and contain nutrients.	FAOSTAT (2022)

Notes: Data from the nine Niger River basin countries from 1986 to 2020 was considered. The choice of period was motivated by the availability of data for all nine countries. There is no missing data; hence, no dataset was corrected through the projection.

4. Empirical results and discussion

The result in Table 2 shows the summary statistics for carbon emissions and food availability in the nine countries of the Niger Basin region in Sub-Saharan Africa.

To obtain the mean, standard deviation, minimum and maximum values, we initially analysed the data for the region as a whole. Then, we disaggregated it for each country to achieve similar objectives at the country-specific level. On a regional level, the average CO_2 emissions per capita in the Niger Basin region was 0.243 metric tons per capita, while the average food availability per capita based on the food production index in the region was 86.50, indicating that the average amount of food production per person in the region decreased by 13.50% from 1986 to 2020 compared to the base period. This also indicates that the Niger Basin region needs to perform better in food production in order to ensure food availability.

When looking at the performance of individual countries, the average carbon emissions per capita for Benin, Burkina Faso, Cameroon, Chad, Cote d’Ivoire, Guinea, Mali, Niger and Nigeria were 0.319, 0.114, 0.289, 0.079, 0.418, 0.201, 0.108, 0.079 and 0.579 metric tons respectively. The result shows that Chad and the Republic of Niger are the countries with the lowest CO_2 emissions from 1986 to 2020, with their emission averaging 0.079 metric tons per capita; while Nigeria, Cote d’Ivoire and Benin are the highest emitters of carbon, as they emit an average of 0.579, 0.418 and 0.319 metric tons per capita. This is higher than the regional average of 0.243. In contrast, the CO_2 emissions per capita of Burkina Faso, Chad, Guinea, Mali and Niger are lower than the regional average.

Table 2: Summary descriptive statistics for carbon (CO_2) emissions and food availability (AVAIL)

Economic region/ country	Variables	Obs.	Mean		SD	Min.	Max.
Niger Basin region	CO_2	315	0.243		0.191	0.012	0.853
	AVAIL	315	86.498	13.5%	13.924	50.58	118.34
Benin	CO_2	35	0.319		0.173	0.101	0.623
	AVAIL	35	84.365	15.6%	13.595	58.39	106.09
Burkina Faso	CO_2	35	0.114		0.061	0.058	0.253
	AVAIL	35	94.572	5.4%	8.471	78.31	109.19
Cameroon	CO_2	35	0.289		0.102	0.177	0.683
	AVAIL	35	77.432	22.6%	14.479	61.51	101.38
Chad	CO_2	35	0.079		0.032	0.012	0.138
	AVAIL	35	80.660	19.3%	17.423	50.58	109.92
Cote d'Ivoire	CO_2	35	0.418		0.119	0.267	0.797
	AVAIL	35	91.497	8.5%	6.369	82.24	105.82
Guinea	CO_2	35	0.201		0.049	0.154	0.344
	AVAIL	35	83.552	16.4%	14.693	65.06	118.34
Mali	CO_2	35	0.108		0.502	0.042	0.187
	AVAIL	35	83.887	16.1%	15.634	65.94	116.14
Niger	CO_2	35	0.079		0.027	0.048	0.131
	AVAIL	35	89.728	10.1%	10.134	67.9	106.99
Nigeria	CO_2	35	0.579		0.156	0.309	0.853
	AVAIL	35	92.793	7.2%	11.511	62.86	111.11

Source: Authors' computation using STATA 16 (StataCorp 2019).
Notes: CO_2 is carbon emissions (proxy for carbon emission per capita); AVAIL is food availability (proxy for gross per capita food production index); Min. is the minimum value; Max. is the maximum value; Obs. is the number of observations; and SD is the standard deviation.

Regarding the availability of food, the result shows that, on average, and despite the poor food production, only Burkina Faso, Nigeria, Cote d'Ivoire and Niger have a better food production index per capita of 94.272 (5.4% less), 92.793 (7.2% less), 91.497 (8.5% less) and 89.728 (10.1% less), respectively, and fared better than the regional average of 86.498 (13.5% less). However, Benin, Mali, Guinea, Chad and Cameroon have a food production index per capita of 84.365 (15.6% less), 83.887 (16.1% less), 83.552 (16.4% less), 80.660 (19.3% less) and 77.432 (22.6% less), respectively on average, which is worse than the regional average. In a nutshell, we found that Cameroon had the lowest average food availability within the region. In contrast, Burkina Faso had the highest food production, followed by Nigeria. Hence, Nigeria had the highest levels of CO_2 emissions per capita and food availability in the Niger Basin region.

The results of the panel convergence methodology for CO_2 emissions and food availability for the Niger Basin region are shown in Table 3. The log-t test was used to determine if there was convergence between CO_2 emissions and food availability in the region. The results showed no significant evidence of overall convergence for CO_2 emission in the region. The t-value for log-t for CO_2 emissions was -1.171, indicating the rejection of the null convergence hypothesis at the 5% level of significance. This evidence agreed with most previous studies, which reported divergence in carbon emissions globally and for low-income nations in particular. However, the whole samples for food availability in the region with t-values for log-t equal to 2.6534 means that we can accept the null hypothesis of convergence in the Niger Basin region.

Table 3: Results for carbon emissions (CO_2) and food availability convergence for the Niger River Basin region

Variables and sample	Countries	β Coeff	S. E.	t-Stat
CO_2 emissions				
Full sample	Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria	-1.171*	0.009	-122.74
First club	Benin, Nigeria	3.501		5.377
Second club	Burkina Faso, Cameroon, Cote d'Ivoire	0.441		4.641
Third club	Guinea, Mali	0.094		0.669
Group four	Chad, Niger	-2.279*		-2.451
Food availability				
Full sample	Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria	2.6534	0.351	7.560
First club	Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Guinea, Mali, Niger, Nigeria	2.6534	0.351	7.560

Note: * implies the rejection of the null hypothesis of convergence at the 5% level

Since the null hypothesis of the convergence of the whole sample for CO_2 emissions was rejected, the study proceeded to test for the formation of a convergence club. The results show that there are four clubs in the region for CO_2 emissions. The first club included Nigeria and Benin; the second club showed that Burkina Faso, Cameroon and Cote d'Ivoire converged; while the third club showed that Guinea and Mali converged. However, the fourth club, comprising Chad and Niger, showed that they did not converge. This therefore implies that the countries in the Niger Basin region are at different levels of CO_2 emissions, which might likely be linked to the human activities/ecological footprint in each country, as each country in the region is on a different path of industrialisation.

Furthermore, we utilised the Phillips and Sul (2009) club-merging algorithm test (robustness test) for CO_2 emissions in the Niger Basin region to ensure accuracy. The outcomes of this test are presented in Table 4.

According to the empirical results in Table 4, there is evidence to support merging the second and third original clubs for CO_2 emissions, since -1.65 is less than the 0.003 (club two + club three) t-stat value. This indicates that clubs two and three are merged to create a larger convergence club; hence, club two now includes Burkina Faso, Cameroon, Cote d'Ivoire, Guinea and Mali. While these counties converge on CO_2 emissions, Chad and Niger, now club three, are diverging.

Table 4: Final club convergence result (club merging) for carbon emissions (CO_2) and food availability in the Niger River Basin

Club merging/ variables/sample	**Countries**	**β Coeff**	**S.E.**	**t-stat**
CO_2 emissions				
Club 1		Full sample accepted		
Final club classification		Full sample accepted		
Food availability				
Club 1+2		-0.557*	0.064	-8.677
Club 2+3		0.003	0.007	0.425
Club 3+4		-0.989*	0.023	-42.436
Final club classifications				
First club	Benin, Nigeria	3.501		5.377
Second club	Burkina Faso, Cameroon, Cote d'Ivoire, Guinea, Mali	0.003		0.425
Group three	Chad, Niger	-2.279*		-2.451

Note: For testing the one-sided null hypothesis, b ≥ 0 against b < 0, we used the critical value: $t_{0.05} = -1.65$ in all cases. S.E. is the standard error, and Stat is statistics.

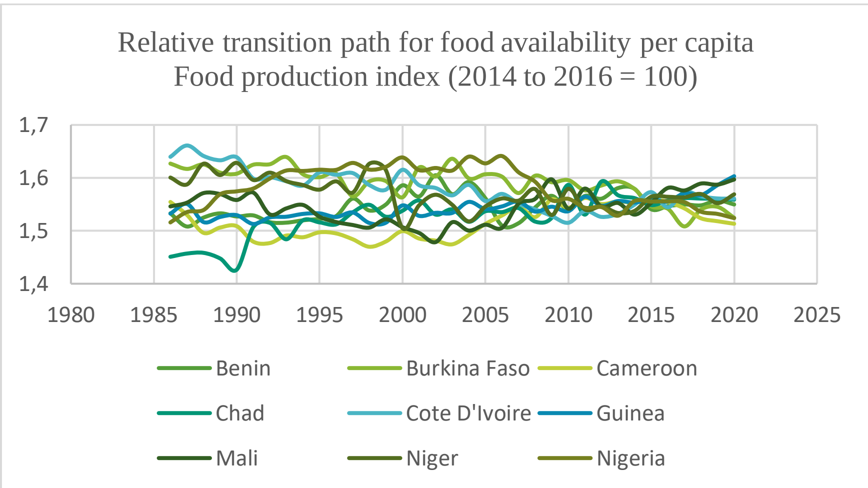

Figure 1: Food availability transition curve for the NBR (full sample)

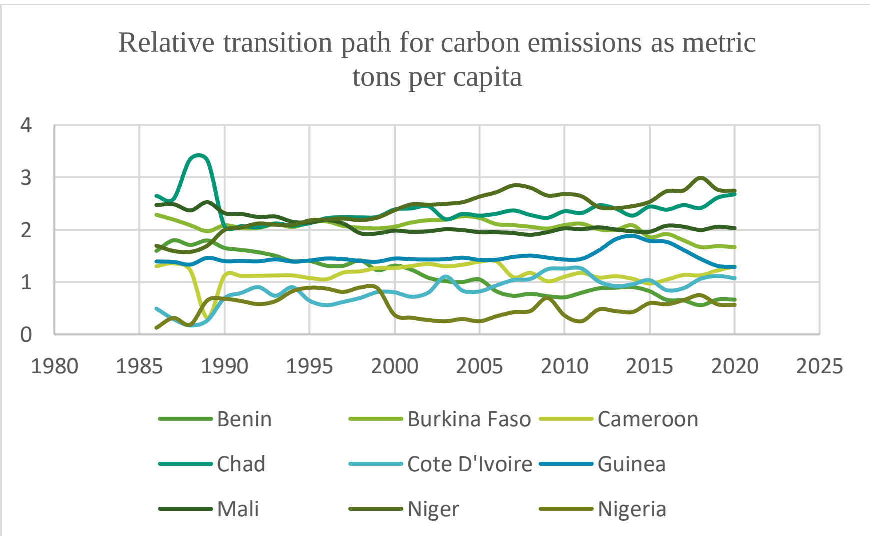

Figure 2: Carbon emissions transition curve for the NBR (full sample)

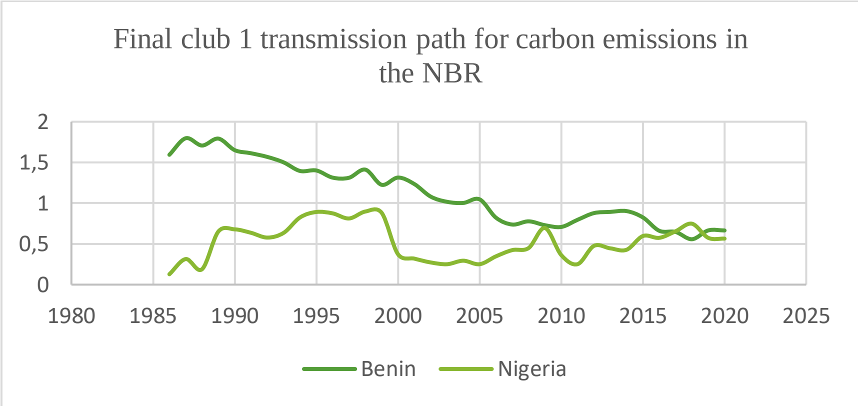

Figure 3: Carbon emissions transition curve for the NBR (club 1)

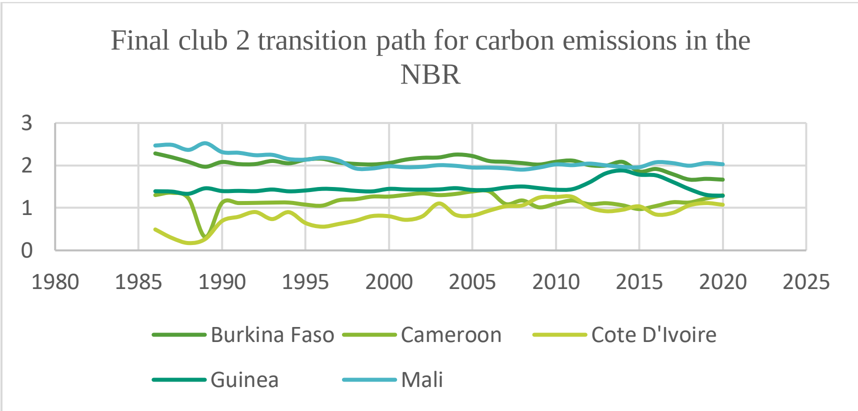

Figure 4: Carbon emissions transition curve for the NBR (club 2)

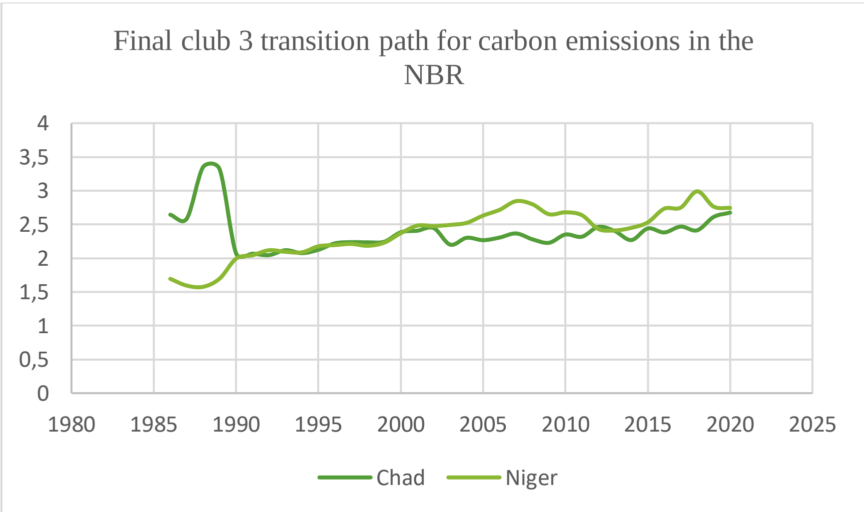

Figure 5: Carbon emissions transition curve for the NBR (club 3)

5. Conclusions and policy implications

The study's convergence club findings indicate the following: (1) there is no evidence of subgroup convergence for food availability in the NBR region, as the region as a whole is converging on food availability; (2) concerning CO_2 emissions, there is no convergence among all countries in the NBR region, but there are three convergence clubs for the region overall, with the third club (Chad and Niger) not showing evidence of convergence; (3) only Nigeria, Cote d'Ivoire and Benin have CO_2

emissions that are above the regional average for the period between 1986 and 2020; and (4) for food availability, only Burkina Faso, Nigeria, Cote D'Ivoire and Niger have production levels that are higher than the regional average for the period between 1986 and 2020.

The study's findings suggest that the convergence club of CO_2 emissions cannot apply generally to the Niger Basin. The lack of full convergence in the entire sample, and the presence of different subgroup convergence clubs for CO_2 emissions, indicate that the individual factors of each country determine their unique course for CO_2 emission policies. The data further supports that these regions have chosen distinct paths to mitigate CO_2 emissions, which could be the reason for the varying levels of transitional paths of CO_2 emission convergence.

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