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Research article

Revisiting the nexus among carbon emissions, energy consumption and total factor productivity in African countries: new evidence from nonparametric quantile causality approach

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ABSTRACT

This study aims to contribute to the existing thin body of nonlinear causality literature by applying the new hybrid nonparametric quantile causality approach. In this line, we investigate the non-linear nexus among total factor productivity, energy consumption and carbon emissions for seventeen African countries. From the results, it is remarkable that there are generally strong causalities between the variables in the middle lower, middle upper and middle quantiles. Hence, energy consumption, environmental pollution and total factor productivity are closely linked in African countries. In particular, bidirectional linkage is detected between total factor productivity and energy consumption for Angola, Benin, Botswana, Cote d'Ivoire, Kenya, Morocco, Egypt, Nigeria and Tunisia. Studying the relationship between total factor productivity and emissions again at the middle quantile bidirectional causal ordering is documented almost for all the countries. Lastly and regarding the linkage between energy consumption and carbon emissions, a strong bidirectional ordering between the two variables is confirmed for Angola, Benin, Cote d'Ivoire, Cameroon, Kenya, Morocco, Egypt, Mozambique, Nigeria, Senegal and Tunisia. We can notice that an increase in economic development is critical for these countries; a number of regulatory policies for environmental problems and energy consumption are required during this development.

1. Introduction

The relationship between economic growth and environmental quality has been discussed for nearly half century, and in line with this, numerous studies have been conducted in the literature on this issue (Roca et al., 2001; Lindmark, 2002; Soytas et al., 2007; Esteve and Tamarit, 2012; Aslan and Gozbasi, 2016; Dogan and Ozturk, 2017; Mikayilov et al., 2018; Zhang et al., 2019; Adedoyin et al., 2019). An extensive literature review is given in Mardani et al. (2019). Since environmental degradation, the most important indicator of which is the increase in carbon emissions, has reached a dangerous level today, the researches in this field remain up to date. According to the 2019 United Nations Global Climate Change Report, greenhouse gas emissions released into the atmosphere reached record levels in the current century. The undesirable development once again raises the importance of the studies on environmental quality, implying that different perspectives are needed in this area, and that new policy implications are inevitable. As a matter of fact, today empirical models investigating the growth-pollution nexus are being revised continuously. In this context, researching the relationship among total factor productivity (TFP) and emissions rather than gross domestic product (GDP) can be considered as an important development discipline.

Economic growth can be explained by the neoclassical and the endogenous growth model. On one hand, neoclassical model stimulates economic growth by capital stocks and population growth. Furthermore, capital stocks and population growth imply decreasing returns to scale and their influence on economic growth is slightly in the long run equilibrium. Hence, exogenous TFP plays an important role on economic growth due to the fact that indicates the level of technological development (Solow, 1957). On the other hand, TFP via the technological change determine a vital role on economic growth adopted by the endogenous growth theories (Lucas, 1988; Romer, 1986). Consequently, both theories agree with the conclusion that TFP boost the performance of sustainable economic growth in the long run.

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Table 1. Summary statistics.

Country	Variable	Mean	SD	Skewness	Kurtosis	JB	PP	KPSS
Angola	TFP	0.293	0.090	-0.431	-3.159	14.024***	-46.706***	0.305*
	EC	497.57	44.94	0.666	-1.021	12.375***	-47.913***	0.726**
	CO_2	0.699	0.318	0.836	-1.826	23.837***	-51.241***	0.088*
Benin	TFP	0.359	0.108	1.685	-2.804	116.38***	-36.147***	0.208*
	EC	349.185	31.665	0.232	-0.568	29.47***	-39.463***	0.233*
	CO_2	0.281	0.166	0.809	-3.910	20.128***	-36.97***	0.122*
Botswana	TFP	0.8	0.117	0.046	-4.692	25.01***	-34.984***	0.278*
	EC	996.653	121.012	0.022	-5.185	6.128**	-40.755***	0.071*
	CO_2	1905	0.568	-0.179	-3.158	7.825**	-39.59***	0.058*
Cote d'Ivoire	TFP	0.729	0.146	0.397	-6.041	12.33***	-39.265***	0.151*
	EC	442.387	69.256	0.830	-4.145	20.657***	-52.235***	0.230*
	CO_2	0.502	0.14	0.548	-4.525	10.778***	-51.951***	0.043*
Cameroon	TFP	0.473	0.106	1.5	4.13	77.329***	-31.027***	0.302*
	EC	399.099	34.269	-1.067	3.032	34.06***	-37.045***	0.302*
	CO_2	0.29	0.165	1.288	4.915	56.325***	-90.544***	0.024*
Gabon	TFP	0.788	0.221	0.354	-3.134	10.157***	-41.896***	0.024*
	EC	1817.712	586.378	0.692	-2.737	14.323***	-35.95***	0.259*
	CO_2	4.624	1.84	1.12	2.191	30.267***	-40.91***	0.078*
Kenya	TFP	0.464	0.089	0.125	-1.524	17.135***	-48.367***	0.356*
	EC	446.47	14.332	1.609	5.297	290.53***	-38.264***	0.421*
	CO_2	0.28	0.054	0.166	-2.857	5.920*	-49.215***	0.066*
Morocco	TFP	0.852	0.258	0.262	-3.483	17.81***	-37.752***	0.086*
	EC	354.477	111.457	0.492	-4.947	13.498***	-47.489***	0.134*
	CO_2	1.094	0.39	0.421	-5.950	11.618***	-50.619***	0.072*
Egypt	TFP	1.02	0.119	0.484	-4.344	7.725**	-50.025***	0.177*
	EC	569.023	210.949	0.039	-6.948	6.327**	-46.851***	0.493*
	CO_2	1.582	0.58	0.183	-5.079	9.198***	-53.173***	0.270*
Mozambique	TFP	0.527	0.103	0.14	-2.082	8.840**	-54.587***	0.048*
	EC	489.044	99.224	1.135	2.082	38.608***	-51.059***	1.963***
	CO_2	0.149	0.096	1.103	-3.142	36.414***	-44.439***	1.075***
Nigeria	TFP	0.701	0.419	0.465	-4.834	11.277***	-49.51***	0.243*
	EC	694.826	53.284	-0.302	-4.383	13.161***	-44.087***	0.153*
	CO_2	0.647	0.19	-0.133	-5.919	6.409**	-49.191***	0.076*
Senegal	TFP	0.693	0.195	0.968	-7.267	28.411***	-35.775***	0.271*
	EC	256.385	27.308	0.046	-7.889	5.553*	-48.489***	0.247*
	CO_2	0.454	0.088	0.508	-6.551	9.716***	-54.892***	0.043*
Togo	TFP	0.248	0.067	0.437	-6.929	9.277***	-45.664***	0.025*
	EC	386.269	59.108	0.17	-1.317	10.455***	-39.379***	0.061*
	CO_2	0.258	0.068	1.245	4.616	39.573***	-39.602***	0.106*
Tunisia	TFP	0.914	0.178	-0.038	-1.481	15.754***	-41.788***	0.352*
	EC	645.907	188.763	0.117	-7.123	9.323***	-57.59***	0.239*
	CO_2	1.769	0.495	-0.161	-4.828	5.518***	-54.963***	0.283*
Tanzania	TFP	0.34	0.082	0.225	-5.805	5.975**	-42.493***	0.115*
	EC	432.363	47.601	0.402	-6.732	8.487**	-31.306***	2.250***
	CO_2	0.126	0.04	1.081	5.428	36.484***	-55.494***	0.371*
South Africa	TFP	0.763	0.079	-0.531	2.054	8.487***	-30.103***	0.185*
	EC	2486.77	237.881	-0.411	-2.600	7.473**	-47.116***	0.119*
	CO_2	8.651	0.849	-0.101	-1.117	9.116***	-47.121***	0.081*
Zimbabwe	TFP	0.668	0.361	-0.314	-3.410	17.171***	-46.43***	0.266*
	EC	857.862	65.894	0.212	-3.166	11.473***	-42.376***	0.173*
	CO_2	1.202	0.327	-0.520	-2.742	11.87***	-51.677***	0.047*

Note: ***, ** and * denote significant at 1%. 5% and 10% level.

Additionally, the relationship between TFP and energy consumption is a more widespread research topic (seen in Tugcu, 2013; Ackah and Adu, 2014; Ladu and Meleddu, 2014; Rath et al., 2019), the relationship between TFP and pollution has more limited literature (see in Amri et al., 2019). Since TFP is the critical crucial criterion for the economic development of the country it belongs to, the relationship TFP-energy-pollution cannot be ignored (Rath et al., 2019). Thus, this study aims to investigate the relationship for African countries. Undoubtedly, the role of African countries in climate change and their development in terms of TFP are taken into consideration in sample selection.

Africa is the second largest continent in the world with large surface area and crowded population, but Africa is a poor continent in terms of

Table 2. Linear Granger causality test.

Country	TFP≠EC	EC≠TFP	TFP≠CO_2	CO_2≠TFP	CO_2≠EC	EC≠CO_2
Angola	3.66***	2.62**	1.58	0.54	0.53	2.54**
Benin	0.40	0.25	0.34	0.46	1.16	1.43
Botswana	2.53**	0.63	1.43	0.07	3.79***	2.22**
Cote d'Ivoire	0.76	1.53	0.32	0.51	0.18	1.07
Cameroon	0.49	0.49	0.32	1.58	0.31	0.34
Gabon	0.94	2.86***	2.46**	1.46	0.36	0.67
Kenya	0.38	2.60**	2.03**	2.13**	1.50	0.90
Morocco	0.21	0.35	0.04	0.86	1.36	0.62
Egypt	0.44	1.50	0.77	0.95	2.32**	0.44
Mozambique	1.75*	1.22	1.41	2.09**	7.43***	4.86***
Nigeria	1.00	0.82	0.41	2.13**	1.24	0.08
Senegal	0.39	1.05	0.93	0.59	2.09**	0.86
Togo	1.16	4.66***	1.06	4.95***	0.93	1.00
Tunisia	1.51	1.22	1.38	0.54	1.10	1.60
Tanzania	0.34	0.09	0.06	0.54	3.56***	2.55**
South Africa	0.89	0.54	0.61	0.55	0.86	2.02**
Zimbabwe	0.08	0.81	2.46**	1.89*	1.01	0.04

Note: ***, ** and * denote significant at 1%. 5% and 10% level.

energy as well as economically. On the other hand, although the continent is home to a large energy source, the increase in energy demand continues, and meeting this increasing demand remains a major problem for almost all African countries. This situation, which means an imbalance between energy supply and demand, is restricted access to clean energy resources on the continent, and is expanded the use of dirty energy resources (Adom et al., 2018). This result inevitably poses a risk of causing an increase in carbon emissions across the continent, and once again emphasizes the link between economic development, energy consumption and pollution in African countries. In addition, according to African Development Dynamics 2018, in terms of TFP, the economic development of the African continent implies that these countries must invest in the fundamental dynamics of long run sustainable growth. TFP across the continent is low and volatile between 1990 and 2016. Moreover, despite the positive developments in capital accumulation in the last fifteen years of this period, there was no growth in TFP. The main explanations of this volatility are external shocks and environmental factors. Therefore, the continent is appeared an environmentally and economically poor development process and in particular economic development should be considered as growth.

The contribution of the present study is two-fold. First, the nexus among total factor productivity, energy consumption and CO_2 emissions are investigated for African countries for first time in the literature. In addition, and more importantly, this paper contributes to the existing thin body of nonlinear causality literature. By applying a new nonparametric causality method, this study aims to increase the limited number of nonlinear causality studies in the related literature, to revisit the mentioned linkage for African countries and to reveal more accurate policy implications. In addition, a number of advantages are listed in the followed approach by Balcilar et al. (2017); the linear causality detection techniques heavily rely on conditional means, and therefore fail to capture the conditional tail distribution of the time series, while the nonparametric quantile causality method eliminates identification errors in that it detects the dependency between time series, this method determines the causality in the tails of the common distribution of variables, and finally investigates the causality in variance. Overall, the current study uses a more advanced technique on causality than recent papers that study African countries in the literature (i.e, Kivyiro and Arminen, 2014; Mensah, 2014; Esso and Keho, 2016; Saint Akadiri et al., 2019; Bekun et al., 2019; Asongu et al., 2020).

The paper is constructed as follows. In Section 2, the data set used in this study is introduced, the basic model is created, and the methodology is explained. The third section summarizes findings and empirical results. Finally, some policy implications are made in conclusion.

2. Data and methodology

In this research we document the non-linear nexus between TFP, EC and CO_2. In particular, we implement annual time series data covering 1971–2014 for seventeen African countries[1]. Due to the limitation of the dataset, the above time period is for twelve countries (Cote d'Ivoire, Cameroon, Kenya, Morocco, Egypt, Mozambique, Nigeria, Senegal, Tunisia, Tanzania, South Africa and Zimbabwe), for Benin, Gabon and Togo time period is from 1980-2014, for Botswana covers 1980–2014 and Angola from 1974 to 2014. Furthermore, in order to have more comprehensive picture of the sample we converted the annual series into quarterly series by employing a quadratic match-sum method.[2] For the research period 1971–2014, TFP dataset has been drawn from the Penn World Table-v9.1 (Feenstra et al., 2015) and for EC (kg of oil equivalent per capita) and CO_2 emissions (metric tons per capita) have been procured from World Bank, World Development Indicators[3].

This study ventures to investigate the underlying nonlinear behavior among TFP, EC and CO_2 for the case of 17 African countries by applying the newly hybrid nonparametric quantile causality procedure of Balcilar et al. (2017). Based on the fashion of Nishiyama et al. (2011) and Jeong et al. (2012), Balcilar et al. (2017) extend their model and established this novel nonlinear quantile causality. More precisely, based on Jeong et al. (2012), we can illustrate the quantile causality as:

As regards a lag vector $(r_{t-1},\dots,r_{t-p},d_{t-1},\dots,d_{t-p})$, r_t does not Granger causes variable d_t in the θ-quantile if

$$Q_\theta\left(r_t|r_{t-1},\dots,r_{t-p},d_{t-1},\dots,d_{t-p}\right)=Q_\theta\left(r_t|r_{t-1},\dots,r_{t-p}\right) \quad (1)$$

and further, d_t may be supposed to Granger causes r_t in the θ-quantile respective to $(r_{t-1},\dots,r_{t-p},d_{t-1},\dots,d_{t-p})$ if

[1] We proposed this sample because of the restriction of data set and more precisely due to the TFP variable: Angola, Benin, Botswana, Cote d'Ivoire, Cameroon, Gabon, Kenya, Morocco, Egypt, Mozambique, Nigeria, Senegal, Togo, Tunisia, Tanzania, South Africa and Zimbabwe.

[2] More information about the advantages of this procedure please see, Shahbaz et al., 2017, Kollias et al., 2018; Shahbaz et al., 2018.

[3] The data can be downloaded from: https://datacatalog.worldbank.org/.

Table 3. BDS results.

Country	Variable	Dimension			
		2	3	4	5
Angola	TFP	45.509***	50.641***	57.166***	66.524***
	EC	49.068***	57.659***	39.749***	-3.015***
	CO_2	37.686***	42.934***	49.951***	60.464***
Benin	TFP	27.056***	26.659***	26.558***	26.865***
	EC	37.385***	97.458***	21.272***	-2.439**
	CO_2	73.730***	100.251***	142.153***	212.565***
Botswana	TFP	72.635***	64.543***	57.466***	51.976***
	EC	-34.616***	-15.230***	-8.931***	-5.979***
	CO_2	32.861***	37.513***	43.577***	52.269***
Cote d'Ivoire	TFP	50.947***	47.557***	44.559***	42.429***
	EC	70.120***	29.607***	78.313***	-7.001***
	CO2	43.164***	42.660***	42.438***	43.207***
Cameroon	TFP	26.120***	24.701***	23.437***	22.621***
	EC	70.028***	608.729***	136.876***	873.091***
	CO_2	29.476***	36.741***	48.229***	65.861***
Gabon	TFP	42.861***	42.926***	43.218***	44.522***
	EC	-8.347***	-3.496***	-1.931*	-2.208**
	CO_2	36.104***	39.184***	43.151***	48.984***
Kenya	TFP	56.035***	50.768***	46.221***	42.764***
	EC	304.960***	597.422***	549.832***	845.015***
	CO_2	41.477***	38.033***	34.951***	32.675***
Morocco	TFP	69.809***	75.922***	83.621***	94.594***
	EC	387.109***	997.038***	289.466***	380.630***
	CO2	61.245***	68.334***	77.577***	90.687***
Egypt	TFP	48.446***	44.203***	43.090***	41.337***
	EC	-7.716***	-3.787***	-2.487**	-1.847*
	CO_2	56.894***	66.646***	79.719***	98.894***
Mozambique	TFP	48.039***	44.246***	40.836***	38.331***
	EC	175.484***	702.179***	383.206***	103.943***
	CO_2	54.852***	69.506***	90.856***	124.011***
Nigeria	TFP	119.84***	180.093***	287.304***	490.295***
	EC	478.849***	136.883***	684.882***	390.415***
	CO_2	39,864***	42,099***	44,945***	49,280***
Senegal	TFP	36.220***	35.793***	35.555***	35.987***
	EC	138.125***	577.261***	656.311***	454.631***
	CO_2	47.974***	43.841***	40.155***	37.373***
Togo	TFP	42.674***	42.701***	43.024***	44.358***
	EC	172.331***	957.638***	129.030***	234.447***
	CO_2	23.451***	22.674***	22.008***	21.732***
Tunisia	TFP	40.407***	37.010***	33.973***	31.764***
	EC	74.685***	178.063***	519.482***	166.366***
	CO_2	32.066***	33.037***	34.341***	36.512***
Tanzania	TFP	40.859***	39.566***	38.504***	38.192***
	EC	189.916***	281.170***	60.495***	35.189***
	CO_2	37.087***	36.744***	36.636***	37.297***
South Africa	TFP	51.160***	49.943***	45.730***	41.730***
	EC	135.097***	-8.787***	-5.462***	-3.879***
	CO_2	460.986***	765.295***	369.096***	674.364***
Zimbabwe	TFP	70.514***	81.836***	96.927***	118.723***
	EC	171.533***	-9.290***	-5.762***	-4.084***
	CO_2	43.438***	45.774***	48.757***	53.314***

Note: ***, ** and * denote significant at 1%. 5% and 10% level.

$$Q_\theta(r_t|r_{t-1},\ldots,r_{t-p},d_{t-1},\ldots,d_{t-p}) \neq Q_\theta(r_t|r_{t-1},\ldots,r_{t-p}) \quad (2)$$

where $Q_\theta(r_t|\cdot)$ is the θ-quantile of. The conditional quantiles of y_t, $Q_\theta(r_t|\cdot)$ depend on t and the quantiles are restricted between zero and one, i.e. $(0 < \vartheta < 1)$.

The implication of the causality in mean from d_t to r_t in the θ-quantile is that the historical values of d_t may assist to predict the values of r_t in the θ-quantile, but not in other quantiles. While testing the causality in the higher order moment, a common complication, which arises, is the k^{th}moment, which commonly insinuates causality m^{th} moment for $k < m$.

Table 4. Results of the Diks and Panchenko (2006).

Country		TFP≠EC	EC≠TFP	TFP≠CO_2	CO_2≠TFP	CO_2≠EC	EC≠CO_2
Angola	m = 2	2391***	1.066	2.104**	1.995**	1.807**	1.883**
	m = 3	2.392***	0.738	1.658**	1.845**	2.339**	1.911**
	m = 4	2.548***	0.283	1.777**	1.845**	2.532***	1.957**
Benin	m = 2	1.920**	-0.571	2.084**	1.173	1.740**	1.852**
	m = 3	1.851**	-0.729	2.094**	1.054	1.602*	1.681**
	m = 4	1.580*	-0.719	2.067**	0.892	1.370*	1.460*
Botswana	m = 2	1.497*	1.499*	1.563*	1.586*	-0.339	1.847**
	m = 3	1.483*	1.456*	1.476*	1.411*	-0.520	1.798**
	m = 4	1.389*	1.414*	1.750**	1.265*	-0.790	1.740**
Cote d'Ivoire	m = 2	1.856**	1.468*	1.919**	2.352***	1.753**	2.048**
	m = 3	1.938**	1.780**	1.786**	2.767***	1.637**	2.270**
	m = 4	2.116**	1.789**	2.161**	2.587***	1.750**	2.786***
Cameroon	m = 2	1.005	1.722**	1.700**	1.319*	-0.642	1.829**
	m = 3	1.155	1.698**	1.407*	1.208	-1.105	1.641**
	m = 4	0.611	1.626**	1.276*	0.861	-1.144	1.741**
Gabon	m = 2	2.096**	1.597*	1.367*	1.636**	0.471	1.295*
	m = 3	1.939**	1.487*	1.201	1.299*	0.721	1.452*
	m = 4	2.067**	1.828**	1.505*	1.529*	0.734	1.330*
Kenya	m = 2	2.169**	2.065**	1.087	1.605*	2.743***	1.788**
	m = 3	2.063**	1.964**	1.097	1.652**	3.230***	2.337***
	m = 4	2.244**	1.631*	1.822**	1.497*	2.661***	2.066**
Morocco	m = 2	1.675**	2.085**	2.076**	2.202**	2.070**	3.210***
	m = 3	1.704**	1.995**	1.998**	2.144**	2.072**	2.954***
	m = 4	1.621*	1.891**	1.860**	1.944**	1.947**	2.721***
Egypt	m = 2	1.781**	1.998**	0.804	2.177**	1.946**	2.497***
	m = 3	1.723**	2.028**	1.215	2.158**	2.027**	2.406***
	m = 4	1.606*	1.793**	1.114	2.134**	2.050**	1.930**
Mozambique	m = 2	1.414**	2.389***	0.271	2.561***	0.672	0.096
	m = 3	1.290*	2.248**	0.350	2.304***	0.692	0.088
	m = 4	1.458*	1.727**	0.117	1.627*	0.641	-0.120
Nigeria	m = 2	1.994**	1.225	2.679***	1.754**	1.593*	2.576***
	m = 3	2.240**	1.279*	2.775***	1.648**	2.167**	2.155**
	m = 4	1.980**	1.276*	2.679***	1.965**	1.992**	2.044**
Senegal	m = 2	1.776**	2.276**	1.671**	1.855**	1.545*	1.878**
	m = 3	1.561*	2.223**	1.179	1.893**	1.585*	1.857**
	m = 4	1.577*	2.089**	1.303*	1.900**	1.570*	1.455*
Togo	m = 2	1.856**	0.968	1.257*	0.068	1.663**	0.701
	m = 3	2.108**	1.634*	1.478*	0.456	1.243*	0.989
	m = 4	2.143**	1.608*	1.550*	1.227	1.806**	0.946
Tunisia	m = 2	2.020**	1.575*	2.366***	1.768**	2.770***	2.415***
	m = 3	1.985**	1.438*	2.274**	1.522*	2.495***	2.325***
	m = 4	1.966**	1.492*	2.141**	1.752**	2.431***	2.352***
Tanzania	m = 2	1.513*	1.937**	2.125**	-0.420	0.937	2.490***
	m = 3	1.406*	1.895**	2.359***	-0.180	0.799	2.450***
	m = 4	1.631*	1.921**	2.679***	0.556	0.871	2.350***
South Africa	m = 2	1.198	2.021**	2.538***	1.231*	1.689**	1.793**
	m = 3	1.325*	2.148**	2.845***	1.067	2.124**	1.901**
	m = 4	1.168	2.087**	1.884**	1.701**	1.915**	2.051**
Zimbabwe	m = 2	1.092	0.866	0.965	1.501*	1.428*	0.961
	m = 3	1.450*	1.377*	1.206	1.531*	1.771**	1.078
	m = 4	1.395*	1.392*	1.619*	1.683**	2.186**	1.553*

Note: m demonstrates the embedding dimension.

The quantile causality in quantile procedure employs a sequential nonparametric Granger causality framework of Nishiyama et al. (2011) to eliminate the stated complication[4].

Apart from the aforementioned econometric tool, we will implement as a robustness test an extra quantile causality framework by Chuang et al. (2009). In a nutshell, Chuang et al. (2009) based on Koenker and Bassett (1978) quantile regression model, we can specify the conditional quantile procedure as:

[4] For more information, see Balcilar et al. (2017).

Table 5. Results of the Balcilar et al. (2017) quantile causality for TFP.

Country	Variable	Quantiles						
		0.05	0.1	0.25	0.5	0.75	0.9	0.95
Angola	EC	1.92*	2.64***	3.88***	4.12***	3.57***	2.11**	1.27
	CO_2	1.49	1.27	3.63***	3.97***	2.17**	0.47	0.48
Benin	EC	1.18	1.89*	2.43***	3.55***	2.75***	1.26	0.75
	CO_2	1.19	1.26	2.46***	2.89***	2.02**	1.09	0.51
Botswana	EC	1.33	2.31**	3.22***	3.28***	3.09***	1.94*	1.15
	CO_2	1.80*	2.26**	2.03**	1.85*	1.99**	1.23	0.63
Cote d'Ivoire	EC	1.47	2.25**	3.53***	4.41***	3.18***	1.96**	1.52
	CO_2	1.42	2.54***	2.54***	3.67***	3.32***	1.24	0.59
Cameroon	EC	2.06**	2.99***	4.10***	5.12***	3.19***	1.94*	1.36
	CO_2	0.32	0.35	1.40	5.92***	6.81***	2.28**	0.90
Gabon	EC	0.02	0.02	0.01	0.00	0.03	0.01	0.02
	CO_2	1.68*	2.37***	3.27***	2.91***	2.17**	1.60	0.54
Kenya	EC	1.87*	2.52***	3.80***	4.51***	3.74***	2.28**	1.31
	CO_2	1.58	1.67*	1.84*	1.85*	1.70*	1.26	0.67
Morocco	EC	2.36***	3.44***	4.51***	4.85***	3.41***	1.71*	0.75
	CO_2	3.04***	4.21***	4.49***	6.60***	2.35***	1.11	0.51
Egypt	EC	3.14***	3.82***	4.19***	4.75***	3.17***	1.87*	1.19
	CO_2	1.61	1.39	3.86***	4.05***	2.23**	0.73	0.29
Mozambique	EC	5.39***	5.30***	5.12***	4.66***	3.58***	1.02	0.32
	CO_2	1.82*	2.05**	2.72***	2.36***	1.94*	1.13	0.55
Nigeria	EC	0.58	1.50	2.34***	2.21**	2.87***	1.89*	0.94
	CO_2	0.87	2.58***	2.62***	3.72***	3.58***	1.54	0.82
Senegal	EC	0.00	0.03	0.00	0.00	0.01	0.00	0.00
	CO2	0.51	1.27	1.15	1.65*	1.61	0.77	0.36
Togo	EC	0.02	0.00	0.01	0.00	0.00	0.01	0.02
	CO_2	0.75	0.87	2.10**	1.40	1.24	1.06	0.69
Tunisia	EC	1.92*	2.29**	3.68***	4.14***	3.19***	1.79*	1.12
	CO_2	0.56	1.86*	2.99***	2.44***	2.80***	1.33	0.51
Tanzania	EC	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	CO_2	1.27	2.05**	3.33***	3.10***	3.67***	1.92*	0.94
South Africa	EC	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	CO_2	0.00	0.03	0.00	0.00	0.00	0.00	0.01
Zimbabwe	EC	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	CO_2	0.53	0.80	5.61***	6.32***	3.82***	1.17	0.48

Notes: ***, ** and * denote significant at 1%. 5% and 10% level.Thecriticalvalues at 10%, 5% and 1% level of significance is 1.645. 1.96 and 2.33 respectively.

$$Q_{va_t}(\tau \setminus x_{t-1}) = c(\tau) + \sum_{i=1}^{p} k_i(\tau) va_{t-i} + \sum_{i=1}^{p} m_i(\tau) vb_{t-i}. \quad (3)$$

and

$$Q_{vb_t}(\tau \setminus x_{t-1}) = d(\tau) + \sum_{i=1}^{p} r_i(\tau) vb_{t-i} + \sum_{i=1}^{p} j_i(\tau) va_{t-i}. \quad (4)$$

in expressions (3(3) and (4)(4),*va* and *vb* are two of the investigated variables (TFP, EC and CO_2), moreover and according to Koenker and Machado (1999) and Chuang et al. (2009), the null hypothesis can be probed by applying the Wald test statistic:

$$\sup_{\tau \in T} W_T(\tau) \to \frac{B_p(\tau)}{\sqrt{\tau(\tau-1)}}^{2} \quad (5)$$

in Equation (5) $W_T(\tau)$ displays the Wald test statistic for quantile $\tau \in [c,d]$, $B_p(\tau)$ shows a vector of p independent Brownian bridges, $B_p(\tau) = [\tau(1-\tau)]^{1/2} N(0, I_p)$. Succinctly, the computational form of sup-Wald test is: $\sup W_T = \sup_{i=1,2,\ldots,n} W_T(\tau_i)$. Lastly, critical values of the sup-Wald test have been found in De Long (1981) and Andrews (2003).

3. Empirical findings

Before we estimate the model, we have to prove if our variables have nonlinear behavior. Initially, we will start with some preliminary tests and with the descriptive statistics (Table 1). Focusing on skewness and kurtosis numbers, we can detect that the majority of the countries have right-skewed distribution (except for three variables) and more precisely, almost all variables distributions have fat tails, kurtosis numbers are bigger than three. The latter indication insinuates a non-normal distribution. Indeed, we can substantiate this result in conjunction with Jarque–Bera test. Jarque–Bera test reject the null hypothesis of normality for all covariates (at least at 5% significance level). Now, we have persuasive proofs that a non-linear test will be useful than applying linear model (Koenker and Bassett, 1978).

Nonetheless and for the sake of completeness, we will follow the relevant literature by assessing traditional linear causality. First, we have to confirm if the variables are stationary. For that reason, Phillips and Perron (1988) and Kwiatkowski et al. (1992) tests are evaluated. The findings of Table 1 suggest that variables are stationary at first difference. The outcomes of linear Granger causality test are illustrated on Table 2. Briefly, we can detect that the neutrality hypothesis is emerging for the plurality of the countries. In particular, Benin, Cote d'Ivoire, Cameroon,

Table 6. Results of the Balcilar et al. (2017) quantile causality for EC.

Country	Variable	Quantiles						
		0.05	0.1	0.25	0.5	0.75	0.9	0.95
Angola	TFP	1.57	2.35***	2.87***	3.16***	2.21***	1.13	0.55
	CO_2	0.98	1.10	5.13***	5.70***	2.73***	0.80	0.50
Benin	TFP	1.26	1.89*	2.59***	2.86***	2.88***	1.49	0.59
	CO_2	1.50	1.64*	3.03***	3.57***	2.34***	0.99	0.46
Botswana	TFP	2.80***	2.96***	2.24**	2.41***	1.83*	0.57	0.33
	CO_2	1.25	1.98**	1.35	1.30	2.07**	1.06	0.47
Cote d'Ivoire	TFP	1.39	1.39	2.19**	2.64***	1.78*	1.21	0.51
	CO_2	1.18	1.96**	2.02**	3.55***	3.36***	0.89	0.37
Cameroon	TFP	2.08**	2.06**	1.17	1.24	1.76*	0.77	0.31
	CO_2	0.28	0.14	1.70*	3.41***	3.11***	0.79	0.31
Gabon	TFP	3.54***	3.44***	3.97***	3.85***	2.67***	1.26	0.60
	CO_2	1.44	1.98**	2.23**	2.08**	2.18**	1.16	0.49
Kenya	TFP	0.80	1.60	3.17***	4.83***	2.73***	1.70*	0.71
	CO_2	1.78*	1.66*	1.99**	3.17***	2.72***	1.17	0.90
Morocco	TFP	8.25***	4.25***	3.24***	2.34***	2.08**	0.91	0.55
	CO_2	3.04***	4.38***	4.48***	6.25***	2.42***	1.29	0.61
Egypt	TFP	1.15	2.64***	4.60***	4.55***	4.89***	2.41***	0.72
	CO_2	1.49	0.79	2.60***	2.90***	1.57	0.53	0.19
Mozambique	TFP	0.55	0.84	1.36	2.16**	2.54***	0.82	0.35
	CO_2	1.41	1.43	2.35***	2.86***	2.87***	1.40	0.51
Nigeria	TFP	2.70***	6.73***	9.87***	8.14***	2.69***	1.22	0.52
	CO_2	0.75	2.08**	2.80***	2.53***	1.91*	0.72	0.53
Senegal	TFP	1.25	1.69*	3.51***	4.25***	3.22***	0.98	0.52
	CO_2	0.83	1.25	1.46	1.57	1.54	0.90	0.63
Togo	TFP	1.00	1.49	1.13	2.58***	2.55***	1.21	0.73
	CO_2	0.52	0.78	1.88*	0.95	0.92	0.99	0.52
Tunisia	TFP	0.67	1.28	2.52***	2.81***	2.35***	1.13	0.49
	CO_2	0.31	1.78*	2.27**	2.19**	1.68*	0.76	0.32
Tanzania	TFP	0.86	2.02**	5.00***	2.80***	2.48***	1.13	0.58
	CO_2	1.25	2.10**	3.38***	2.82***	3.40***	2.02**	0.80
South Africa	TFP	1.22	1.96**	1.36	2.82***	2.51***	1.74*	0.52
	CO_2	0.00	0.03	0.00	0.00	0.00	0.03	0.01
Zimbabwe	TFP	0.60	1.04	1.98**	4.69***	2.86***	1.48	0.80
	CO_2	0.64	0.83	5.39***	8.05***	4.75***	1.71*	0.63

Notes: ***, ** and * denote significant at 1%. 5% and 10% level. The critical values at 10%, 5% and 1% level of significance is 1.645. 1.96 and 2.33 respectively.

Morocco and Tunisia do not demonstrate evidence of causality among the variables, while Egypt, Nigeria, Senegal and South Africa depict merely one unidirectional causality. CO_2 causes EC for Egypt and Senegal, the contrary interconnectedness is supported for South Africa and one-way relationship running from CO_2 to TFP is endorsed for Nigeria. Tanzania and Zimbabwe represent bidirectional linkage for the pairs CO_2 – EC and TFP – CO_2, respectively. Gabon and Kenya exhibit one-way relationship from EC to TFP, whilst Gabon displays the same direction from TFP to CO_2. Also, Kenya emerges two-way direction for the variables TFP and CO_2. When it comes to Togo CO_2 causes TFP and EC provokes TFP. Regarding the latter linkage, the reverse sign is documented for Botswana, while reciprocal relationship between CO_2 and EC is emerged for the same country. Likewise, the identical behavior for CO_2 and EC for Mozambique and one-way interconnectedness from TFP to EC and from CO_2 to TFP is depicted for the same country. Lastly, Angola shows two-way causality between TFP and EC, whereas we can observe unidirectional causality running from EC to CO_2.

However, as we discussed earlier, a nonlinear tool conceivably is more appropriate than a linear model. Consequently, Diks and Panchenko (2006) nonlinear Granger causality test is applied. Furthermore, we conduct another pretest in order to confirm the underlying nonlinearity among the series. Hence, utilizing a test for independence established by Broock et al. (1996, BDS test), we secure that series have nonlinear stream. Table 3 depicts the outcomes of BDS test reckoned at different embedding (m) dimensions. As illustrated, we cannot reject the null hypothesis of identically independently distributed (at the 1% significance level) which means that variables are nonlinear and the linear causality test is not suitable. The estimated finding of the nonlinear Granger causality methodology of Diks and Panchenko (2006, DP test) are described in Table 4. By and large, we will not focus on the outcomes with scrutiny, because DP test takes into consideration solely the mean of the sample and we would like a more comprehensive picture of the dataset. However, we can mention the existence of the bidirectional causality for the majority of the countries. Notably is the fact that every country shows at least two significant causalities among the variables for all embedding dimensions employed.

The outcomes of nonlinear quantile causality established by Balcilar et al. (2017) are documented in Tables 5, 6, and 7. First, we demarcate the quantiles at seven levels $(0.05, 0.10, 0.25, 0.50, 0.75, 0.90 and 0.95)$ and we categorized them at five groups; lower quantiles$(0.05 and 0.10)$, middle lower quantile(0.25), middle quantile (0.50), middle upper quantile (0.75) and upper quantiles$(0.90 and 0.95)$. A cursory glance at the results unveil a strong association among the covariates at middle lower, middle upper and middle quantiles for all the countries, these findings imply sturdy connection between the pertinent variables. Starting with nexus between TFP and EC (Tables 5 and 6), we can

Table 7. Results of the Balcilar et al. (2017) quantile causality for CO_2.

Country	Variable	Quantiles						
		0.05	0.1	0.25	0.5	0.75	0.9	0.95
Angola	EC	1.83*	2.48***	3.96***	3.90***	3.18***	1.86*	1.22
	TFP	2.50***	3.33***	4.54***	2.72***	1.84*	0.88	0.59
Benin	EC	0.86	1.46	2.65***	3.14***	2.75***	1.30	0.80
	TFP	1.07	1.93	3.73***	3.54***	3.74***	1.04	0.42
Botswana	EC	0.98	1.74*	2.62***	3.15***	3.03***	2.03**	0.95
	TFP	3.23***	3.38***	2.03**	2.27**	1.91*	0.57	0.29
Cote d'Ivoire	EC	1.65*	2.72***	3.93***	4.94***	3.66***	2.13**	1.79*
	TFP	1.08	0.86	2.03**	4.51***	2.83***	1.31	0.60
Cameroon	EC	1.97**	2.87***	3.88***	4.24***	3.02***	1.97**	1.39
	TFP	2.32**	2.36***	1.81*	2.05**	1.57	0.92	0.52
Gabon	EC	0.02	0.02	0.01	0.00	0.03	0.01	0.02
	TFP	2.63***	2.29**	2.88***	2.87***	2.31**	1.14	0.54
Kenya	EC	1.97**	2.65***	4.11***	4.67***	3.81***	2.32**	1.35
	TFP	1.08	2.48***	3.49***	4.57***	2.90***	1.59	0.56
Morocco	EC	2.21**	3.20***	3.74***	4.88***	3.36***	1.67*	0.73
	TFP	7.86***	4.72***	3.49***	2.48***	2.17**	0.97	0.52
Egypt	EC	3.04***	3.95***	4.23***	4.63***	3.22***	1.83*	1.16
	TFP	1.18	2.73***	4.84***	4.60***	4.89***	2.41***	0.72
Mozambique	EC	5.37***	5.29***	5.12***	4.70***	3.56***	1.02	0.33
	TFP	0.66	1.07	2.08**	2.84***	2.04**	0.60	0.33
Nigeria	EC	0.50	1.31	1.72*	2.72***	2.92***	1.78*	0.97
	TFP	1.52	6.54***	10.55***	8.72***	3.35***	1.46	0.61
Senegal	EC	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	TFP	1.52	2.36***	3.61***	3.37***	2.66***	0.64	0.38
Togo	EC	0.02	0.00	0.01	0.00	0.00	0.01	0.02
	TFP	1.52	1.90*	1.98**	2.88***	2.63***	1.21	0.66
Tunisia	EC	1.25	1.62	2.71***	3.48***	2.82***	1.32	0.81
	TFP	0.75	1.31	2.39***	2.44***	2.33***	1.15	0.50
Tanzania	EC	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	TFP	1.00	1.97**	3.51***	2.83***	2.18**	0.94	0.52
South Africa	EC	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	TFP	1.42	2.27**	2.06**	2.39***	2.04**	1.30	0.37
Zimbabwe	EC	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	TFP	0.45	0.69	1.15	4.75***	2.33***	1.20	0.43

Notes: ***, ** and * denote significant at 1%. 5% and 10% level.The criticalvalues at 10%, 5% and 1% level of significance is 1.645. 1.96 and 2.33 respectively.

mention a bilateral causal ordering between of them established at middle lower, middle upper and middle quantiles for Angola, Benin, Botswana, Cote d'Ivoire, Kenya, Morocco, Egypt, Nigeria and Tunisia. This bilateral linkage between economic development (TFP) and energy consumption insinuates that possible rise of TFP will exert the same influence on EC and vice versa. Moreover, economic development can be achieved by increasing countries' energy consumption levels (and the vice versa) on the aforementioned African countries. This means, absorption of more natural resources (inter alia, water, land, energy and soil) from the production process due to the rising of economic activities. Our outcomes are in line with Esso (2010) for Cote d'Ivoire, Kais and Mbarek (2017) for Egypt and Tunisia, Solarin and Shahbaz (2013) for Angola and Wolde-Rufael (2006) for Egypt and Moroccobut they are in contradiction with the findings of Odhiambo (2010) and Mensah (2014) for Kenya and Wolde-Rufael (2005) for Egypt, Cote d'Ivoire who discovered one-way linkage running from energy consumption to economic growth and Wolde-Rufael (2006, 2009) for Benin with the vice versa relationship. The results at the upper quantiles yield neutrality hypothesis with slight variation, for instance, we can observe partially (only at 90thquantile) two-way linkage for Kenya and Egypt, while a unidirectional causal relationship at (90th) upper quantile from TFP to EC is statistically significant finding for Angola, Botswana, Cote d'Ivoire and Morocco. A reverse ordering is yielded solely for South Africa. The neutrality outcome between TFP and EC is not surprisingly, owing to the fact that the majority of our sample belongs to the Sub Saharan regions and Sub Saharan countries have the lowest levels of energy efficiency (Akinlo, 2008). In the case of the lower quantiles, bidirectional statistically significant association between TFP and EC is found for Cameroon and Morocco and partially bidirectional linkage (at 10th quantile) for Angola, Botswana and Egypt, a unidirectional association is running from TFP to EC is observed for Kenya, Mozambique and Tunisia, whilst a reverse casual ordering is mentioned for Gabon, Nigeria, Senegal, Tanzania and South Africa. Studying the relationship between TFP and CO_2 (Tables 5 and 7) again at the middle quantile bidirectional causal ordering is documented almost for all the countries (Angola, Benin, Botswana, Cote d'Ivoire, Cameroon, Gabon, Kenya, Morocco, Egypt, Mozambique, Nigeria, Tunisia, Tanzania and Zimbabwe), except for Senegal and South Africa (from CO_2 to TFP). The feedback signs imply that as economic development increase the governments would have environmental problems and the opposite. This indicates, rising scales of air pollution can be activated from the positive relationship between natural resources and economic activities. The results of mutual nexus are in tandem with Esso and Keho (2016) for Gabon, Shahbaz et al. (2015) for Botswana, whereas they are in opposition to Esso and Keho (2016) for Benin, Cote d'Ivoire, Nigeria, Kivyiro and Arminen (2014) for Kenya and Mensah (2014) for Nigeria and Egypt who displayed one-way

Table 8. Results of the Chuang et al. (2009) quantile causality for TFP.

Country	Variable	[0.05,0.95]	[0.05,0.5]	[0.5,0.95]	[0.05,0.1]	[0.25,0.5]	[0.5,0.75]	[0.75,0.9]	[0.9,0.95]
Angola	EC	11.45 [1]**	6.82 [1]	22.09 [9]	6.18 [1]	2.89 [1]	2.16 [1]	2.67 [1]	21.97 [9]
	CO_2	18.64 [1]**	20.23 [3]***	29.11 [10]**	20.23 [3]***	17.82 [1]***	40.00 [10]***	29.10 [10]**	23.84 [1]***
Benin	EC	24.50 [1]***	22.13 [1]***	16.33 [5]	21.74 [1]***	16.21 [6]	17.16 [56]**	10.75 [6]*	16.40 [5]
	CO_2	27.54 [1]***	28.24 [1]***	11.96 [1]**	28.80 [1]***	25.44 [1]***	7.52 [1]**	3.55 [5]	23.45 [5]***
Botswana	EC	13.72 [1]***	13.83 [1]***	16.62 [5]	13.69 [1]***	10.10 [1]**	8.03 [1]**	10.54 [1]**	16.79 [5]
	CO_2	7.82 [1]	35.85 [6]***	3.65 [1]	4.11 [5]	17.58 [6]*	10.53 [6]	16.52 [6]	3.64 [1]
Cote d'Ivoire	EC	9.08 [1]*	9.19 [1]*	3.18 [1]	1.33 [1]	20.00 [4]***	4.48 [2]	4.76 [2]	3.18 [1]
	CO_2	7.92 [6]	6.72 [6]	3.46 [3]	1.06 [1]	2.90 [6]	3.57 [6]	2.29 [6]	2.23 [3]
Cameroon	EC	35.13 [1]***	3.67 [1]	33.45 [1]***	3.71 [1]	0.99 [1]	0.17 [1]	0.65 [1]	30.98 [1]***
	CO_2	47.87 [1]***	11.90 [1]**	49.07 [1]***	7.53 [1]	46.06 [3]***	39.53 [6]***	94.84 [6]***	49.75 [1]***
Gabon	EC	8.18 [2]	7.92 [2]	5.62 [3]	0.52 [1]	3.87 [1]	2.06 [1]	1.01 [1]	5.71 [3]
	CO_2	9.32 [1]**	31.52 [6]***	31.65 [6]***	21.62 [4]**	45.46 [2]***	24.32 [6]***	16.96 [6]	1.76 [1]
Kenya	EC	9.20 [1]**	9.61 [1]**	10.28 [3]	9.68 [1]**	2.53 [1]	9.62 [6]	7.07 [6]	11.29 [5]
	CO_2	10.23 [1]**	4.18 [5]	3.00 [1]	4.05 [5]	2.27 [5]	3.29 [2]	0.86 [1]	3.09 [1]
Morocco	EC	16.76 [6]	16.45 [6]	5.88 [6]	17.96 [2]***	11.53 [5]	5.98 [6]	5.89 [6]	6.01 [5]
	CO_2	12.26 [1]**	12.35 [1]**	2.21 [1]	12.65 [1]**	17.21 [4]**	4.95 [10]	2.22 [1]	0.92 [1]
Egypt	EC	21.71 [1]***	22.15 [1]***	3.26 [1]	3.59 [1]	21.80 [1]***	7.87 [1]	1.69 [3]	2.36 [1]
	CO_2	12.63 [1]**	12.45 [1]**	4.32 [1]	1.91 [1]	0.88 [2]	3.95 [5]	4.89 [5]	3.46 [1]
Mozambique	EC	21.62 [5]**	14.20 [1]***	1.20 [1]	43.74 [2]***	8.82 [1]	3.02 [1]	0.27 [1]	1.22 [1]
	CO_2	41.06 [1]***	40.13 [1]***	24.18 [1]***	42.85 [1]***	19.09 [5]**	15.26 [2]**	11.87 [2]*	24.65 [1]***
Nigeria	EC	10.09 [5]	9.45 [5]	4.56 [1]	10.91 [5]	2.86 [4]	3.41 [1]	1.39 [2]	4.56 [1]
	CO_2	4.53 [1]	4.67 [1]	28.17 [6]***	4.69 [1]	2.78 [1]	0.54 [1]	0.79 [1]	28.75 [6]***
Senegal	EC	15.94 [1]***	16.11 [1]***	8.88 [3]	16.41 [1]***	3.61 [2]	12.64 [1]**	2.03 [5]	9.06 [3]
	CO_2	22.72 [6]**	7.54 [1]	16.62 [6]	7.45 [1]	4.72 [1]	3.91 [5]	4.58 [6]	17.67 [6]
Togo	EC	3.64 [1]	3.75 [1]	0.50 [1]	3.74 [1]	1.71 [1]	1.84 [5]	0.27 [1]	0.96 [1]
	CO_2	13.86 [2]**	18.12 [3]***	14.16 [2]**	20.26 [3]***	6.65 [1]	1.03 [1]	6.66 [6]	14.06 [2]**
Tunisia	EC	96.80 [6]***	26.94 [6]***	95.45 [6]***	19.81 [5]**	25.59 [6]***	12.13 [6]	23.74 [6]**	75.05 [6]***
	CO_2	78.56 [2]***	26.31 [2]***	74.06 [2]***	16.03 [6]	8.85 [6]	5.75 [2]	21.39 [1]***	51.56 [2]***
Tanzania	EC	12.28 [1]**	12.36 [1]**	2.83 [1]	12.52 [1]**	10.23 [1]**	7.40 [1]	1.27 [1]	3.70 [1]
	CO_2	21.44 [6]*	21.75 [6]*	6.51 [3]	12.79 [3]	20.51 [2]***	7.69 [6]	3.96 [6]	6.55 [3]
South Africa	EC	53.42 [10]***	31.41 [10]**	54.80 [10]***	4.67 [2]	14.46 [10]	9.22 [10]	12.37 [8]	55.27 [9]***
	CO_2	22.50 [10]	16.06 [10]	23.10 [10]	6.25 [1]	9.96 [10]	6.17 [10]	9.71 [10]	23.38 [10]
Zimbabwe	EC	11.68 [1]**	1.36 [1]	11.49 [1]**	1.39 [1]	7.75 [5]	3.77 [4]	11.79 [6]	12.06 [1]**
	CO_2	26.70 [5]***	13.37 [5]	8.90 [1]*	13.86 [5]	12.81 [5]	5.97 [5]	11.93 [6]	9.04 [1]*

Notes: ***, ** and * depict significant at 1%, 5% and 10% level. Sup-Wald test statistics and the selected lag order (in square brackets) are presented.

nexus running from economic growth to CO_2 emissions. The finding of South Africa is similar to Bekun et al. (2019) and it is contradicting outcome with Menyah and Wolde-Rufael (2010), Kohler (2013) and Lin et al. (2014) who revealed the neutrality hypothesis between the two variables. At the upper levels, one-way linkage running from TFP to CO_2 is found for Cameroon and Tanzania and one-way from CO_2 to TFP for Cote d'Ivoire and Egypt. At lower quantiles, three countries (Botswana, Gabon and Morocco) emerge two-way nexus, also three countries (Kenya, Mozambique and Tunisia) confirm unidirectional causal ordering running from TFP to CO_2, and the vice versa linkage for Angola, Cameroon, Kenya and Egypt.

Analyzing the linkage between EC and CO_2 (Tables 6 and 7), a strong bidirectional ordering between the two variables is regenerated at middle lower, middle upper and middle quantiles for Angola, Benin, Cote d'Ivoire, Cameroon, Kenya, Morocco, Egypt, Mozambique, Nigeria, Senegal and Tunisia. This bilateral ordering is not surprisingly for the Sub-Saharan African countries, the proportion of the nonrenewable sources is over than 80% for the majority of the counties and the air pollution plays a vital role with almost 4000 premature deaths per day (Keho, 2016). Furthermore, another possible clarification for this nexus is that Sub-Saharan's energy mix is dominated by fossil fuels with the resultant effect of CO_2 emissions. Accurately, this outcome indicates that increasing energy consumption the environmental degradation will be more harmful for the atmosphere and a potential rise of CO_2 emissions exert increasing of energy consumption. The governments can modify the traditional energy sources (such as fossil fuels) with energy conservation technologies – renewable energy sources (inter alia solar panels, wind power and hydro power plant) or they can substitute it with clean renewable systems for higher environmental quality. Likewise, with latter nexus, we can trace it at lower quantile for Kenya Morocco and for Cote d'Ivoire and Botswana (but only at 10^{th} level). Last year's air pollution is a major difficulty for African countries. For example, the exacerbation of GHGs emissions has as a consequence the adoption of renewable energy sources instead of nonrenewable. Therefore, African governments anticipate a positive effect of renewable sources on environmental performance levels (Kivyiro and Arminen, 2014; Keho, 2016; Esso and Keho, 2016). On one hand, a statistically significant nexus running from CO_2 to EC is created at lower quantiles for Angola, Cameroon, Egypt and Mozambique, at upper quantiles merely for Cote d'Ivoire and at middle and at 25^{th}quantile for Botswana. On the other hand, a weak vice versa connection is identified at 10^{th}quantiles for Gabon, Nigeria and Tanzania. According to Mensah (2014), African countries have large proportion of fossil fuels (such as oil and coal), as the result our positive influence of EC on CO_2 emission is not surprisingly. Lastly, the neutrality hypothesis between the two variables is supported by Senegal, South Africa and Togo at the middle quantile. This is outcome is similar to Lin et al. (2014) and Bekun et al. (2019) who verified the neutrality hypothesis in Africa. Lastly, the controversy between all

Table 9. Results of the Chuang et al. (2009) quantile causality for EC.

Country	Variable	[0.05,0.95]	[0.05,0.5]	[0.5,0.95]	[0.05,0.1]	[0.25,0.5]	[0.5,0.75]	[0.75,0.9]	[0.9,0.95]
Angola	TFP	20.86 [1]***	11.46 [2]*	20.80 [1]***	7.28 [2]	34.85 [10]***	14.02 [10]	16.23 [1]***	21.86 [1]***
	CO_2	83.83 [10]***	41.63 [10]***	81.43 [10]***	1.45 [1]	6.74 [1]*	13.25 [10]	84.16 [10]***	31.97 [10]**
Benin	TFP	19.72 [1]***	2.95 [1]	20.14 [1]***	3.02 [1]	13.75 [6]	2.62 [6]	5.35 [6]	20.00 [1]***
	CO_2	22.97 [1]***	6.19 [2]	20.13 [1]***	6.21 [2]	3.10 [4]	13.55 [1]***	7.57 [9]	22.97 [1]***
Botswana	TFP	6.05 [1]	10.75 [4]	6.35 [1]	15.58 [5]	7.36 [4]	0.49 [1]	3.29 [1]	6.42 [1]
	CO_2	15.52 [1]***	15.63 [1]***	18.89 [6]	15.41 [1]***	14.80 [1]***	8.20 [1]**	5.38 [6]	15.03 [1]***
Cote d'Ivoire	TFP	21.04 [1]***	15.94 [5]	21.13 [1]***	16.06 [5]	1.72 [1]	1.50 [1]	0.78 [2]	21.72 [1]***
	CO_2	50.70 [2]***	11.47 [5]	49.73 [2]***	10.92 [5]	5.54 [1]	1.98 [1]	13.97 [2]**	26.05 [1]***
Cameroon	TFP	16.13 [6]	15.54 [6]	6.82 [1]	5.10 [2]	7.82 [6]	5.25 [6]	7.63 [6]	6.93 [6]
	CO_2	55.13 [6]***	74.13 [6]***	10.29 [1]**	2.07 [1]	61.05 [6]***	71.56 [6]***	14.24 [6]	8.55 [1]*
Gabon	TFP	23.37 [1]***	24.15 [1]***	21.86 [1]***	0.75 [1]	4.27 [3]	22.85 [1]***	19.83 [1]***	21.81 [1]***
	CO_2	13.43 [1]***	16.42 [2]**	13.54 [1]***	3.73 [1]	2.23 [4]	7.71 [1]	8.07 [1]**	13.78 [1]***
Kenya	TFP	53.09 [6]***	52.31 [6]***	57.11 [6]***	4.76 [1]	5.82 [1]	31.92 [6]***	18.32 [6]	21.93 [5]**
	CO_2	28.34 [10]*	10.51 [10]	28.30 [10]*	5.10 [1]	10.57 [10]	4.35 [10]	4.32 [10]	28.55 [10]*
Morocco	TFP	21.39 [5]**	9.97 [5]	12.52 [6]	10.28 [5]	8.29 [5]	9.26 [10]	3.56 [6]	12.84 [6]
	CO_2	40.01 [10]***	23.99 [7]***	38.10 [9]***	31.04 [5]***	9.90 [10]	5.17 [10]	14.57 [10]	42.70 [9]***
Egypt	TFP	57.93 [4]***	6.63 [3]	17.91 [1]***	4.30 [3]	3.09 [5]	9.13 [6]	8.18 [6]	52.03 [4]***
	CO_2	68.84 [4]***	5.29 [1]	65.13 [4]***	11.79 [3]	1.71 [1]	3.83 [1]	3.57 [1]	60.45 [4]***
Mozambique	TFP	4.13 [1]	4.91 [2]	4.34 [1]	5.07 [2]	13.144 [6]	0.45 [1]	0.84 [1]	4.39 [1]
	CO_2	29.48 [5]***	19.86 [5]**	30.89 [5]***	20.21 [5]**	14.64 [5]	6.74 [5]	5.01 [5]	31.21 [5]***
Nigeria	TFP	52.94 [6]***	51.46 [6]***	17.60 [6]	17.44 [5]	47.96 [6]***	27.25 [6]***	8.07 [6]	17.67 [6]
	CO_2	17.31 [6]	17.85 [6]	7.26 [3]	17.54 [6]	16.56 [6]	8.74 [6]	0.58 [1]	41.02 [11]***
Senegal	TFP	9.79 [1]**	9.89 [1]**	8.01 [1]*	15.65 [2]**	2.40 [1]	4.55 [1]	80.1 [1]*	5.57 [1]
	CO_2	27.29 [6]***	26.01 [7]**	18.56 [6]	26.45 [7]**	13.82 [9]	4.25 [6]	2.64 [6]	18.41 [6]
Togo	TFP	20.15 [2]***	14.67 [6]	21.65 [2]***	3.87 [1]	10.50 [6]	10.80 [6]	1.87 [5]	19.86 [2]***
	CO_2	10.56 [3]	4.43 [5]	9.59 [3]	9.15 [9]	8.40 [7]	7.91 [10]	4.77 [10]	10.61 [3]
Tunisia	TFP	10.02 [1]**	10.31 [1]**	3.91 [1]	8,19 [1]*	10.55 [1]**	10.18 [6]	6.09 [6]	3.94 [1]
	CO_2	26.51 [4]***	25.74 [4]***	15.87 [3]**	37.26 [5]***	24.08 [3]***	3.81 [1]	1.85 [3]	16.05 [3]**
Tanzania	TFP	17.42 [10]	16.68 [10]	15.72 [10]	10.75 [1]**	14.68 [10]	16.99 [10]	17.33 [10 [	15.83 [10]
	CO2	67.80 [10]***	65.13 [10]***	62.01 [10]***	38.26 [6]***	27.20 [10]*	11.91 [10]	16.36 [10]	60.55[10]***
South Africa	TFP	29.19 [10]**	29.45 [10]**	18.49 [10]	12.67 [1]**	14.40 [10]	9.96 [10]	10.95 [10]	18.77 [10]
	CO_2	11.64 [5]	1.53 [2]	11.77 [5]	0.19 [2]	5.61 [5]	7.09 [6]	3.48 [6]	10.63 [5]
Zimbabwe	TFP	23.93 [5]***	23.99 [5]***	8.52 [3]	10.68 [3]	15.84 [5]	4.02 [5]	1.90 [1]	8.62 [3]
	CO_2	6.28 [1]	6.03 [1]	4.85 [1]	10.05 [3]	6.33 [1]	3.90 [2]	1.20 [6]	26.09 [6]***

Notes: ***, ** and * depict significant at 1%, 5% and 10% level. Sup-Wald test statistics and the selected lag order (in square brackets) are presented.

findings are mainly due to the methodological perspective, as we pointed out this is the first study which employ the new hybrid nonparametric quantile causality approach. The quantile causality versus conventional causality test is such that preceding test is reliable in the case of separate sample periods (quantile levels) and/or separate framework specifications. Hence, we cannot have similar results with the majority of the relevant literature because the classical Granger causality test is used by the majority of research. Finally, another vital reason is the time period.

As a supplementary examination of the main evidence, we implement an extra non-linear quantile concocted by Chuang et al. (2009). The empirical results are depicted in Tables 8, 9, and 10. The findings of the robustness test certify some of the main results and especially in middle quantile but in most cases the results show a weak link. The vital discrepancies between the two models are at lower and upper quantiles. For example, employing Chuang et al. (2009) fashion we can remark a statistically significant connection between TFP and CO_2 at upper quantiles for Angola, Benin, Cameroon and Nigeria, whilst at lower quantiles for Benin. Concerning the EC and CO_2 nexus, two-way relationship is found at upper levels for Botswana, Morocco, Mozambique, Nigeria, Tanzania and Zimbabwe. At the vice versa quantiles (5^{th} and 10^{th}) ordering is displayed for Morocco and Tunisia. Noteworthy is the nexus between TFP and EC at lower levels, where reciprocal causal relationship is emerged for Senegal and Tanzania. Ultimately, the use of the supplementary substantiation does not play a comparative role but a complementary role in order to detect an entire picture of the relationship among the variables.

4. Conclusion and policy implications

Africa, which is the second most populous continent in the world, is known for have some structural problems in economic terms. In addition, while the continent's energy supply security problems and environmental sustainability constraints are particularly noteworthy, there are limited studies in the literature for African countries. The aim of this study is to provide fresh evidence the TFP-CO_2-EC nexus in seventeen African countries. For this purpose, the causal relationships between three variables are examined from different quantiles for TFP-EC, TFP-CO_2 and EC-CO_2, respectively.

While investigating these three causal connections, nonparametric quantile causality method developed by Balcilar et al. (2017) is adopted as a current methodology. We focused on the results from this method to make some policy implications. With this method, both nonlinear relationships are investigated and the situation of the relationships between variables in different quantiles can be examined. While general conclusions are presented for medium quantile levels considering all of Africa, country-specific comments may be made with the results obtained

Table 10. Results of the Chuang et al. (2009) quantile causality for EC.

Country	Variable	[0.05,0.95]	[0.05,0.5]	[0.5,0.95]	[0.05,0.1]	[0.25,0.5]	[0.5,0.75]	[0.75,0.9]	[0.9,0.95]
Angola	EC	18.54 [6]	12.45 [6]	18.99 [6]	7.43 [1]	7.88 [6]	5.28 [6]	8.75 [6]	22.07 [6]**
	TFP	18.66 [10]	19.07 [10]	7.10 [1]	7.22 [1]	18.59 [10]	1.16 [1]	6.45 [1]	7.16 [1]
Benin	EC	10.20 [6]	10.55 [6]	8.54 [6]	10.84 [6]	9.86 [6]	3.61 [6]	3.87 [6]	8.67 [6]
	TFP	22.98 [6]**	22.18 [6]**	39.49 [10]***	23.01 [6]**	16.24 [10]	6.65 [10]	3.48 [10]	40.43 [10]***
Botswana	EC	47.42 [6]***	11.93 [6]	47.15 [6]***	0.86 [1]	7.02 [6]	6.89 [6]	8.25 [6]	44.13 [6]***
	TFP	23.44 [6]**	22.90 [6]**	23.98 [6]**	0.47 [1]	1.52 [1]	5.27 [6]	1.88 [1]	23.44 [1]***
Cote d'Ivoire	EC	15.56 [5]	7.23 [5]	15.13 [5]	5.90 [5]	7.46 [5]	5.50 [5]	6.42 [5]	15.77 [5]
	TFP	22.62 [6]**	8.42 [6]	22.95 [6]**	5.61 [1]	8.49 [5]	7.08 [5]	3.83 [5]	22.62 [6]**
Cameroon	EC	47.26 [6]***	46.63 [6]***	42.67 [6]***	15.28 [1]***	22.16 [6]**	8.25 [6]	7.20 [6]	48.32 [6]***
	TFP	92.90 [6]***	83.91 [6]***	71.41 [6]***	51.47 [1]***	81.09 [6]***	73.93 [6]***	5.87 [6]	28.50 [1]***
Gabon	EC	1.45 [1]	6.19 [3]	1.12 [1]	4.74 [3]	1.47 [1]	0.84 [1]	0.55 [1]	1.12 [1]
	TFP	48.34 [6]***	11.11 [6]	47.85 [6]***	0.45 [1]	5.55 [6]	4.20 [6]	3.19 [6]	45.13 [6]***
Kenya	EC	16.88 [6]	16.89 [6]	12.64 [6]	22.77 [1]***	11.84 [6]	4.57 [6]	18.70 [10]	55.12 [10]***
	TFP	28.40 [6]***	29.41 [6]***	19.87 [6]**	29.77 [6]***	19.95 [6]**	10.27 [6]	8.65 [6]	19.55 [6]**
Morocco	EC	67.77 [6]***	24.90 [6]***	26.38 [1]***	18.33 [3]***	15.83 [6]	3.44 [6]	10.49 [1]**	26.49 [1]***
	TFP	39.38 [6]***	35.78 [6]***	15.84 [6]	14.96 [5]	21.63 [6]**	7.54 [6]	2.98 [6]	17.69 [6]
Egypt	EC	53.57 [6]***	22.08 [6]**	50.74 [6]***	10.47 [1]**	18.26 [6]*	8.77 [6]	11.80 [6]	55.84 [6]***
	TFP	16.56 [6]	15.46 [6]	15.35 [6]	1.51 [3]	14.51 [6]	13.55 [6]	7.54 [6]	15.05 [6]
Mozambique	EC	24.22 [6]**	18.83 [6]	28.77 [1]***	6.46 [1]	18.97 [6]*	3.05 [4]	5.76 [6]	29.29 [1]***
	TFP	17.91 [6]	16.85 [6]	12.41 [6]	4.23 [1]	11.63 [6]	4.35 [6]	3.68 [6]	12.41 [6]
Nigeria	EC	29.75 [6]***	24.11 [6]**	28.96 [6]***	24.13 [1]***	19.49 [6]**	19.00 [6]**	13.41 [6]	30.48 [6]***
	TFP	16.31 [1]***	14.01 [5]	17.10 [1]***	14.45 [5]	31.82 [6]***	12.94 [1]***	9.51 [1]	17.06 [1]***
Senegal	EC	53.88 [6]***	13.99 [6]	98.01 [10]***	7.76 [3]	7.80 [6]	6.21 [1]	15.90 [10]	52.59 [4]***
	TFP	13.15 [6]	13.41 [6]	13.04 [6]	13.17 [5]	8.86 [6]	3.00 [6]	5.40 [6]	13.11 [6]
Togo	EC	11.68 [6]	10.85 [6]	10.95 [6]	14.79 [3]*	9.70 [6]	4.27 [6]	3.23 [6]	13.32 [6]
	TFP	41.70 [6]***	31.28 [6]***	40.83 [6]***	12.17 [3]	15.59 [6]	9.03 [6]	10.23 [6]	2.99 [1]
Tunisia	EC	51.18 [10]***	20.32 [3]***	25.22 [10]	19.50 [3]***	20.81 [3]***	9.81 [1]**	13.90 [10]	18.43 [7]
	TFP	41.84 [6]***	40.78 [6]***	12.34 [6]	4.20 [1]	14.94 [6]	8.59 [6]	5.49 [6]	12.39 [6]
Tanzania	EC	59.04 [6]***	58.46 [6]***	35.92 [6]***	3.14 [1]	33.02 [6]***	5.71 [6]	5.61 [6]	36.01 [6]***
	TFP	18.51 [6]	14.08 [6]	18.32 [6]	12.23 [5]	9.96 [5]	7.10 [6]	11.99 [6]	18.96 [6]
South Africa	EC	38.06 [10]***	18.85 [10]	37.45 [10]***	20.69 [7]*	15.34 [10]	3.46 [10]	6.59 [10]	36.13 [10]***
	TFP	14.07 [6]	6.13 [6]	14.55 [6]	3.70 [3]	6.18 [5]	5.35 [6]	4.71 [6]	13.97 [6]
Zimbabwe	EC	38.11 [10]***	21.42 [6]**	39.45 [10]***	22.38 [10]	16.06 [9]	2.71 [6]	10.40 [9]	37.23 [10]***
	TFP	44.20 [6]***	19.43 [6]	43.65 [6]***	25.06 [8]**	17.08 [6]	13.46 [6]	10.68 [6]	47.79 [6]***

Notes: ***, ** and * depict significant at 1%, 5% and 10% level. Sup-Wald test statistics and the selected lag order (in square brackets) are presented.

from other quantile levels. This is the most important methodological innovation of the method and provides more detailed results unlike current literature.

From the results, it is remarkable that there are generally strong causalities between the variables in the middle lower, middle upper and middle quantiles. Hence, energy consumption, environmental pollution and total factor productivity are closely linked in African countries. This result justified the use of TFP instead of GDP as an indicator of economic development. While the increase in economic development is critical for these countries, a number of regulatory policies for environmental problems and energy consumption are required during this development. Otherwise the carbon emission and energy consumption caused by the increase in TFP renders the economic development unsustainable. Given the strong causality between TFP and energy consumption, it is inevitable that economic development lead to energy consumption in most of these countries, but shifting to renewable resources in the use of energy resources may alleviate the problem. Africa, the richest continent in the world in terms of natural resources, should invest in areas where it will use these resources more efficiently in order not to lose this advantage. Otherwise, even if it improves economic development, it will not be long run. Hence, policy-makers should take into account the two strands of total factor productivity, labor productivity and capital productivity. For example, changing traditional energy sources such as fossil fuels (coal) and non-renewable electricity consumption, which they are harmful for the environment, countries can increase (energy) capital productivity by investing to modern energy conservation technologies (inter alia solar panels, wind power and hydro power plant), this technological change from advanced technologies and technological innovations not only can ameliorate total factor productivity but also the reduction of the air pollution. Moreover, increasing employees with skillful qualifications in energy saving, each country can anticipate raise of economic development (through labor productivity) and raise of energy efficiency.

In addition to obtaining the opportunity to make general inferences for the Africa continent as a whole, more specifically, evidence has been provided to lead some policy implementations in particular for countries. First of all, the mutual causal relationships that we encountered of TPF-CO_2, TPF-EC and EC-CO_2 illustrated that Angola, Benin, Cote d'lviore, Kenya, Morocco, Egypt, Nigeria and Tunisia have an important place in the study. Therefore, development, pollution and energy consumption in these countries have a structure nourishing to each other. In particular, the relationship between total factor productivity and carbon dioxide emission should be considered as a starting point for policymakers. The development in production efficiency leads to environmental pollution, which means that environmentally friendly investments for energy, an important production input, are insufficient. The prevalence of traditional energy consumption in these countries, particularly, in rural areas, is also a disadvantage, and a social policy should be implemented to raise awareness and educate users. Therefore, not only economic but also social measures should be included in the policymaking processes of these countries. Also, Angola and Nigeria, which are oil exporting countries, are dependent on fossil fuels due to these features. Hence the results achieved are not surprising for these countries, but this should not be their fate. For this reason, it is almost imperative for these countries to transfer the obtained energy export revenues to sustainable areas. Of course, the availability of the infrastructural problems of these countries is an undisputed reality (Egypt can be excluded), but it may be a good alternative to engage in multinational agreements to overcome this.

It is known that South Africa is one of the leading countries in carbon emissions in the continent. However, the validity of the neutrality hypothesis has been determined in terms of EC-CO_2 nexus at the medium quantiles. Moreover, the results revealed the accuracy of the conservation hypothesis between CO_2-TFP in South Africa. Accordingly, an improvement in TFP does not necessarily reduce carbon emissions in this country. From the validity of the neutrality hypothesis, it is understood that carbon emission and energy consumption are not an important component of each other. The results are surprising for this country, where fossil energy consumption is high, but in direct proportion with this feature, it shows that a number of goals (determined at the Paris conference) are implemented and delivered results. It is thus emphasized that international agreements and aid are crucial to combat climate change.

The most striking result of the analysis is that no unidirectional nonlinear causal relationship from energy consumption to carbon emission is encountered. Moreover, unidirectional causality from CO_2 emissions to energy consumption is detected in Angola, Cameroon, Egypt and Morocco at lower quantiles. This result reflects the effect of carbon dioxide emission on energy consumption estimates in these countries. Therefore, policies that do not have a direct relationship with energy consumption in the fight against climate change actually affect energy consumption. Also, the decrease in energy consumption or fossil energy consumption will contribute to the reduction of pollution in the long run. Therefore, it can be said that reducing emissions will reduce energy consumption, but it not can be said that energy conservation policies have no impact on the environment.

As a future investigation, we believe that the nexus among total factor productivity, energy consumption and CO_2 emissions is at the beginning and researchers can scrutinize this relationship with precision.

Declarations

Author contribution statement

Eyup Dogan: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Panayiotis Tzeremes: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Buket Altinoz: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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