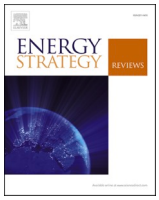
Energy Strategy Reviews 48 (2023) 101109



Contents lists available at ScienceDirect

Energy Strategy Reviews

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



Refugees, traditional energy consumption, environmental pollution, and deforestation: Fourier BARDL method

Melike E. Bildirici [a], Rui Alexandre Castanho [b], Gualter Couto [c], Sema Yılmaz Genç [a,*]

[a] Faculty of Economics and Administrative Studies, Davutpaşa Campus, Yıldız Technical University, Esenler, Istanbul, 34220, Turkey
[b] Faculty of Applied Sciences, WSB University, 41-300, Dabrowa Górnicza, Poland
[c] School of Business and Economics and CEEAplA, University of Azores, 9500-321, Ponta Delgada, Portugal

ARTICLE INFO

Handling Editor: Mark Howells

Keywords:
Refugee population
Environmental pollution
Deforestation
BARDL with Fourier
FBARDL
Causality with Fourier

ABSTRACT

After 2010, refugees through the World peaked at the highest level since WW II. Most of this increment was realized between 2011 and 2015 years in the effect of the Syrian conflict and the Arabic spring, and refugee problem that is an important problem for the world emerged. This problem was analyzed in the macroeconomic dimension, in the health dimension by different studies. However, the energy and environmental economy dimensions of this problem has not been adequately analyzed.

This paper explored the cointegration and Granger causality between the refugee population, traditional energy consumption(firewood, charcoal, and coal), economic growth, environmental pollution, and deforestation by the tests of Fourier Bootstrapping ARDL (FBARDL) and Granger causality with the Fourier method in the period 1985–2020 in Ethiopia, Sudan, and Uganda. Firstly, whether the series is stationary was investigated by using Fourier unit root tests. Then, the FBARDL test determined the evidence of cointegration among the variables. Finally, by applying Granger causality with the Fourier method, the evidence of unidirectional causality running from the refugee population and traditional energy consumption to deforestation and evidence of unidirectional causality running from the refugee population and traditional energy consumption to environmental pollution were determined. The analysis results draw attention to the impacts of the increasing refugee population on deforestation, and environmental pollution. Governments must develop their long-term environmental policies in the context of the effects of refguee population on sustainability.

1. Introduction

In the 21st century, environmental pollution and refugees problem are very important problems, and scientists, politicians etc. force to give more and more attention to sustainable environment. Environmental pollution has been analyzed in many studies. Especially in the context of the EKC hypothesis, many studies have discussed the shape of the EKC curve, while others have emphasized its causes. However, the studies analyzing these causes did not elaborate on refugees, which are important among the causes. However, refugees, which are an important problem for all countries in the world, are important in terms of environmental problems. These movements realized by humans lead to the burden on the world's natural resources, especially forest areas of developing and underdeveloped countries. Deforestation is increasing in the effect of the rapid growth of the world's population, migration, the rise of industry, and the use of traditional energy (wood, charcoal, coal, etc.). Among the factors leading to deforestation, refugees are the focus of this paper.

In some parts of the world, refugee movements affect environmental pollution and deforestation because refugees and host households are highly dependent on forests and other woodlands as sources of woodfuel for cooking and for income generation, contributing to their livelihood resilience. The average daily consumption of firewood by the refugees is very high rate [1]. [2] declared A refugee cuts [down] around 20 trees per year. According to Ref. [3], the average daily consumption of firewood by refugees in northern Uganda is 1.6 kg per person, and among host communities, 2.1 kg. [1] accented that the refugee influx from South Sudan has led to an increase in the rate of degradation and tree loss, both inside the West Nile refugee settlements and around their boundaries, with accelerated land cover changes in bushland and woodland. Deforestation and forest degradation are not new phenomena in Uganda, but the refugee presence has added to existing pressures on

* Corresponding author.
E-mail address: sygenc@yildiz.edu.tr (S. Yılmaz Genç).

https://doi.org/10.1016/j.esr.2023.101109
Received 7 December 2022; Received in revised form 11 May 2023; Accepted 7 June 2023
Available online 19 June 2023
2211-467X/© 2023 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

the environment due to increased demand for wood as cooking fuel. So competition for available resources could become a source of tension between the refugees and host communities.

Refuges cause increasing deforestation in a few ways. Firstly, the demand for traditional energy in camps leads to deforestation since traditional energy (wood, coal, and charcoal) is mostly used for heating and food preparation [4]. Secondly, it is to obtain arable lands because the primary purpose of most people living in rural areas is survival, and they mostly depend on agriculture. Forest areas are used to open up arable land. The third factor is barter because refugees are forced to barter or sell some food to get some firewood. Wood is sold, and barter is made. Another factor comes from the use of forests for house construction. The last factor of deforestation is political and institutional. Due to the increasing population caused by refugees, governments' road investments can directly affect deforestation rates. In this condition, they are the most critical determinant of the growing resource scarcity and environmental damage. Especially, traditional energy consumption, which is the first of the factors listed above, causes environmental pollution because these traditional stoves are the reason for the consumption of a huge amount of traditional energy, such as wood, charcoal, coal, or animal waste. Consumption of traditional energy emits some contaminants such as combustion products (CO2), incomplete combustion products (asPAHs (polycyclic aromatic hydrocarbons) including BaP(benzo[*a*]pyrene), organic carbon (OC), black carbon (BC), CO, and), and high-temperature reaction products (as NOx), particulate matter (PM)), fuel contaminants (asSO2 and metals), etc. [5–7]. The contribution of traditional cooking devices to environmental pollution is at the moment unclear, but some papers found that the contribution of BC changes in the range of 27–55% [8,9]. According to Ref. [10], the average emission factor of BC for coal burned is 0.002 g/kg. Undoubness, the CO_2 emissions of refugees are a small number of global emissions, but ~13 million tons of CO_2 activities annually [11,12]. In 2014 throughout the world, the ineffective consumption of energy by refugees released 14.3 million tonnes of tCO_2 [13]. Furthermore, as accented by Ref. [14], current energy in refugee settlements is unsafe, unproductive, and polluting. According to International Energy Agency [15], CO_2 emissions throughout the world rose 33.1 billion tons in 2018, which is approximately 145% above the pre-industrial levels. Moreover, the CO_2 growth rate from 2015 to 2016 was the largest of the last 30 years, and the CO_2 concentration rate was the highest in the last 800,000 years [16]. This state shows that the energy cost of living is increasing (*The notion of the energy cost of living was suggested in the 1970s* [17]*, although the carbon footprint has been explored in recent years.* [18] *showed that GHG releases are an important part of the process of consumption and production, and they provided a framework to explain this connection*).

The impacts of refugees on deforestation and CO_2 emissions have not been analyzed simultaneously. Many papers analyzed the relationship between energy consumption-environmental pollution especially in the context of EKC hypothesis. A few papers analyzed the relationship between migration and natural resources. Although the importance of the population on environmental pollution was emphasized by Ref. [19], it lagged behind other causes of pollution. Using the panel quantile autoregressive distributed lag (PQARDL) and causality methods for the 1996–2019 period [4], concentrated on the relationship between refugees population, governance and sustainable environment for Bangladesh, Ethiopia, Jordan, Lebanon, Pakistan, Sudan, and Uganda. But this article did not use traditional energy consumption. To our knowledge, this is the first article to investigate environmental pollution, deforestation, refugees, economic growth and traditional energy consumption in the context of the cointegration and Granger causality in time series data. Our main goal is to fill the gap in the literature. In this paper, in Ethiopia, Sudan, and Uganda, which have the highest population of refugees or asylums throughout the World, cointegration and Granger causality between the refugees, traditional energy (firewood, charcoal, and coal) consumption, economic growth, CO_2 emissions, and deforestation will be explored through three different methods for the period 1985–2020 by two different models. The reasons for choosing the two different models can be explained as follows. If a single model covering all variables is established, a single ecm coefficient would be obtained. The two models enable to obtain of separate ecm coefficients for deforestation and environmental pollution. In addition, short and long-term coefficients will be obtained for each model. Another reason is the shortness of the period; while the cointegration is tested in short period it is the statistical limitations of a large number of variables.

The methods chosen will be applied as follows. Firstly, to determine stationary was applied the ADF with the Fourier method (FADF) and the NL with the Fourier method (F–*tNL*) tests suggested by Ref. [20]. Secondly, FBARDL and causality test with Fourier methods can remove some degenerate cases from ARDL method. So the motivations for employing these methods are i. that this method permits endogeneity, feedback, and moreover, and ii. when the analysis period is short, employing non-linear methods can cause some econometric problems. The establishment of the Fourier model is significant for eliminating gradual breaks in the models because it does not require knowing the exact frequency of breaks and break dates. The benefit of these tests is that the power of the estimation is unaffected by the break date, number, or form. However, if the samples cover relatively short periods, the use of nonlinear approaches like NARDL, MSVAR, TARDL, and LSTARARDL for existence of break in data could result in many econometric issues in the estimation [21]. Employing the BARDL with the Fourier approach is encouraged as it does not presume a particular functional form, exact frequencies, or prior knowledge of the dates [22,23].

This paper was designed as follows: in the second section, the literature review is explained, and the relationship between the refugee population and deforestation is explained in the third section, the methodology and data are presented. In the section explains the results. In the fifth section, a discussion is given. The conclusion is given in the last section.

2. Literature review

The damaging impacts of economic growth and energy consumption on environmental pollution have been accented by many papers in pursuit of Grossman-Krueger [24]. Some of them contributed to the EKC hypothesis. But these papers did not explore the effect of population and natural resources on environmental pollution due to the complexity of population relations. Howeover, the relationship between population and natural resources has attracted the attention of economists since the study conducted by Malthus [19]. Thus [19], began to research the relationship between population and resources. [25] brought up this connection once more (1864). In colonial Africa, land for agriculture was explored by Refs. [26,27]. [28] concentrated on concerns related to the environment, food production, and population increase. In their model of the relationship between population and environment, [29] anticipated that the world would overshoot its carrying capacity in the model of the relationship between population and environment they developed. The relationship between population and environment was also covered by Ref. [30]. According to Ref. [31], there can be environmental harm in locations where many refugees live. The population pressure hypothesis was reviewed by Ref. [32].

On the other hand, in some papers, Population-driven productivity growth [33] may result in an upward movement along the environmental Kuznets curve(EKC) [34], especially if higher food demand leads to land clearing for agricultural expansion [35]. The resulting environmental damages may be highly concentrated around camp areas in the absence of sufficient transportation infrastructure [36]. But population growth does not always result in forest loss [37], as these processes will vary based on differences in country policy [38]. Some studies, however, have discussed the causes [39–41]. In the frame of refugees, there are markets within each refugee camp [42], these results suggest that income-generating forest extraction could manifest several kilometers from the camp itself.

Some studies have highlighted the impact of population on deforestation while investigating the impact of population on the environment [43]. accented that this population pressure on the environment can lead to land erosion, increased energy consumption, air, and water pollution increased land use, decreased productivity of cultivated land, increased deforestation, etc. A few papers accented that the population contributes more to deforestation than other factors [44]. For example [45], found that most deforestation cases are driven by population growth. On the other hand, due to the complexity of population relations as well as political issues, population problems [46] were not taken into account in the formulation of environmental problems. However, these authors continued to study this topic. Several researchers, including [47–50], and [51,52], have discussed the factors that contribute to environmental issues like deforestation, land degradation, and the depletion of forest resources as a result of migrants' pressure on the local forest.

Some other studies have discussed the causes of deforestation. According to Refs. [53,54], one of the primary reasons for deforestation is the demand for traditional energy due to the massive amounts of firewood, charcoal, and coal used for heating and cooking in refugee camps. [12] highlighted trade as a further element because refugees are required to barter or sell some food to obtain firewood. [55]' research in Kenya also revealed that almost 25% of food was traded for firewood . [56] found that rapid population growth and immigration from Mozambique raised trees' demand for fuel, arable land, and investment in livestock. According to Ref. [56], the increasing population leads to deforestation, landlessness, and overgrazing. [57] explained the impacts of refugees on the environment. According to Ref. [57], while refugees expect external support, they are forced to depend on the forest for cooking, makeshift shelters, etc. And deforestation emerges from the use of wood for fuel and shelter. [58] emphasized the population mass in a refugee camp is the central factor in environmental damage. [51] also found that the location of a camp is a significant factor in determining the impacts of refugees on the environment, and accented refugee camps that are established in border areas or existing towns cause competition for restricted sources such as fertile land, water, wood, etc … . [59] discussed significant relationships between camp proximity and deforestation. [35] extended their analysis by processing all spatial data at a much finer spatial resolution (1.1 km by 1.1 km) and examined *where*, in relationship to the camp, forest losses occur.

The extent of deforestation was examined in some articles in the literature. [60]showed the effects of 3.5 Million Afghan refugees on the environment in Pakistan and determined that refugees from north of the Hindukush produced the most extensive degradation. [61] investigated the effects of human activity on the forests in Pakistan and Britain. Natural resource availability in Western Kenya decreased by 11.8% between 1997 and 2014, according to Ref. [62]. The most significant resource loss between the two observations was calculated to be −7.96% for the years 2010–2014. Natural resource depletion was calculated to be 11.8% between 1997 and 2014. In Eastern Chad [63], examined how the savanna ecology changed from 2007 to 2017 in close proximity to the refugee camp. They discovered that 2008 saw the most resource utilization, and 2010 and 2011 experienced the greatest resource loss [64]. emphasized that hundreds of tons of wood are consumed daily in Tanzanian refugee camps, which are entirely dependent on energy from nearby forests. [65] looked into the deforestation caused by the camp's expansion from March to December 2017. They estimated that 573 ha, or around 11% of the research area, were exposed to deforestation. According to Ref. [66], from July 2016 to February 2018, 2283 ha of forest were destroyed. According to Ref. [67], on August 25, 2017, over 1 million refugees from Myanmar crossed the border into Bangladesh, causing deforestation and the growth of the Kutupalong refugee camp.

Some studies emphasized the relationship between refugees, and environmental pollution. [4] explored causality between refugees, governance, sustainable environment, economic growth, energy consumption, supplementary explanatory variables, HDI, the trade deficit, and financial development for Bangladesh, Ethiopia, Jordan, Lebanon, Pakistan, Sudan, and Uganda using the panel quantile autoregressive distributed lag (PQARDL) and causality methods for the 1996–2019 period. Long-run coefficients found by the PQARDL method showed evidence of the long-run relationship between the sustainable environment, refugee population, governance, economic growth, energy consumption, and explanatory variables. Both traditional and [68] causality tests determined the evidence of unidirectional causality from political and economic governance to greenhouse gas (GHG) emissions and deforestation, as well as a unidirectional causality from refugees to GHG emissions and deforestation.

[69] accented the relation between refugees and environmental pollution; on the other hand [70,71], accented that refugees do not have severe impacts on the environment [72]. discussed the relationship between movements for refugees and the environmental damages they posed in refugee camps. According to Ref. [37], the population growth rates of countries in Asia, Latin America, and Africa promote the conversion of forests into arable land because the survival of the vast majority of people living in rural regions depends mainly on agriculture. Kenya's population density and agricultural output were examined by Ref. [27]. Based on Pakistan's recent productivity rates and firewood collection operations [73], discovered the evidence favoring the vicious circle hypothesis. According to Ref. [74], tropical deforestation has sizable effects on GHG emissions. [44] also highlighted various issues. They contend that migration—which settled agricultural households do by sending their young families to the border as migrants—is the primary cause of the destruction of border forests in several nations. According to Ref. [75], accentuated forests are destroyed more quickly in impoverished areas. The effects of immigration on forests and woods have been studied by Refs. [76–79], and [80] in countries such as Sierra Leone, Nepal, Sri Lanka, Ethiopia, Kenya, and Rwanda. According to research by Ref. [81], the rapid increase in population in developing nations is a major factor in the ongoing deforestation [82]. suggest that logging activities to produce wood as an alternative source of fuel energy for things like kerosene and cooking gas, or power, can lead to deforestation.

In the literature, the impacts of refugees on deforestation and CO_2 emissions have not been analyzed simultaneously. This paper aimed to fill the gap in the literature.

3. *Methods and data*

3.1. *Research questions*

The research questions are in two dimensions. First dimension is regarding the effects of refugees population on the deforestation and environmental pollution. Does refugees population and traditional energy consumption of refugees population have environmental pollution and deforestation? Second dimension is on the econometric method. What are the directions of causality between economic growth, traditional energy consumption, refugees population, deforestation, environmental pollution?

3.2. *Motivation and research methodology*

The motivation of the study is to evaluate cointegration and causality between refugees population, the deforestation and environmental pollution, traditional energy consumption and economic variables by using FBARDL and Fourier Granger causality methods. FBARDL method is used to decide the existence of cointegration among the variables and the Fourier Granger causality test are employed to assess the direction of causalities. These tests have the advantage that the date of, the number of, and the form of the break do not affect the power of the estimation [83]. Additional, literature assessing cointegration to investigate long-run relationship under the presence of nonlinear breaks suggested nonlinear cointegration methods; the Asymmetric ARDL, MSVECM,

ThresholdARDL, and LSTARARDL etc. However, the nonlinear methods can cause to several econometric issues in estimation when data cover relatively short periods. So, in the existence of breaks and when the analysis period is short, the FBARDL method provides important advance in modeling and the method does not assume a specific functional form. And the method does not need a-priori knowledge about the dates of the breaks. The proposed Fourier BARDL model effectively eliminated the degenerate cases accented by BARDL method.

3.3. Fourier BARDL method and fourier causality method

ARDL method provides the upper and lower bounds for the critical values (CV). However, FBARDL supplies the CV (See Ref. [84] for BARDL). And it investigates the presence of noncointegration, cointegration, and degenerate situations, and unlike the BARDL test, it does not require knowing the exact frequency of breaks and break dates. FBARDL bound approach is given as follows:

$$\Delta A_t = c_0 + \sum_{i=1}^{m} \gamma_i \Delta A_{t-i} + \sum_{j=1}^{n} \varphi_j \Delta B_{t-j} + \delta_1 A_{t-1} + \delta_2 B_{t-1} + \gamma_{11} \sin\left(\frac{2\pi nt}{T}\right) + \gamma_{12} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t \tag{1}$$

$$\text{Where } \delta_1 = -\left(1 - \sum_{i=1}^{p} \alpha_i\right); \delta_2 = \sum_{j=1}^{q} \beta_j \tag{2}$$

We used supplementary tests proposed by Ref. [84] for the BARDL test. In their approach, the usage of three tests is compulsory to determine the presence of any from noncointegration, cointegration, and degenerate cases. The cointegration between A and B requires the rejection of three null hypotheses. Case-1: F-test for $H_0 : \delta_1 = \delta_2 = 0$ against $H_1 : any\ \ \delta_1, \delta_2 \neq 0$. Case-2 *t*-test for $H_0 : \delta_1 = 0$ against $H_1 : \delta_1 \neq 0$. Case-3 F test for $H_0 : \delta_2 = 0$ against $H_1 : \delta_2 \neq 0$.

The representation of the error correction model (ECM) is achieved after reparameterization and,

$$\Delta y_t = \varphi_i + \sum_{k=1}^{p} \gamma_j \Delta y_{t-j} + \sum_{k=0}^{q-1} \mu_j \Delta x_{t-j} + \vartheta_j \left(y_{jt-1} - \varphi_j x_{jt}\right) + \gamma_{11} \sin\left(\frac{2\pi nt}{T}\right) + \gamma_{12} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t \tag{3}$$

the inclusion of two Fourier terms γ_{11} and γ_{12} and γ_{11} and γ_{12} aim at capturing the structural changes and nonlinearities. The Fourier terms are tested with the null hypothesis $H_0 : \gamma_{11} = 0, \gamma_{12} = 0$ against the alternative $H_1 : \gamma_{11} \neq 0, \gamma_{12} \neq 0$ and the calculated *F, Fourier* test statistic follows an *F* distribution with *q,* and *n-h*-1° of freedom under the null where *n* is the sample size and *h* is the total number of parameters in the model estimated.

3.4. Fourier causality test

Granger causality method with Fourier can be rewritten by including ECM term. If cointegration between the selected variables can be determined. Granger causality with the Fourier method can be given as follows

$$\Delta y_t = \lambda_1 + \sum_{i=1}^{n} \alpha_{1i} \Delta y_{t-i} + \sum_{k=1}^{m} \beta_{1k} \Delta x_{t-k} + \gamma_1 \sin\left(\frac{2\pi nt}{T}\right) + \gamma_{11} \cos\left(\frac{2\pi nt}{T}\right) + \zeta_1 ecm_{t-1} + \varepsilon_{1t} \tag{4}$$

$$\Delta x_t = \lambda_2 + \sum_{i=1}^{n} \alpha_{2i} \Delta x_{t-i} + \sum_{k=1}^{m} \beta_{2k} \Delta y_{t-k} + \gamma_2 \sin\left(\frac{2\pi nt}{T}\right) + \gamma_{21} \cos\left(\frac{2\pi nt}{T}\right) + \zeta_2 ecm_{t-1} + \varepsilon_{2t} \tag{5}$$

where ε_t is i.i.d and $\sigma^2\ \varepsilon(0,\infty)$; and ζ is the parameter defining the speed of adjustment to the long-run equilibrium after a shock. The error correction mechanism to occur ζ should be statistically significant and non-positive in the range of $-1 < \zeta < 0$. The short-run Granger non-causalities are tested under the null hypotheses of $H_0 : \beta_{1k} = 0$ in the first vector and $H_0 : \beta_{2k} = 0$ in the second vector against the alternatives of $H_0 : \beta_{1k} \neq 0$ and $H_0 : \beta_{2k} \neq 0$, respectively, inrEq.'s (8) and (9) for all *i*.

3.5. The model

In this study, two separate models the included explanatory variable sets are estimated. **Model 1** is an FBARDL model with three explanatory variables,

$$\Delta for_t = \varphi_i + \sum_{j=1}^{p} \lambda_j \Delta for_{t-j} + \sum_{i=0}^{n-1} \mu_i \Delta y_{t-i} + \sum_{k=0}^{z-1} \mu_k \Delta rf_{t-k} + \sum_{m=0}^{k-1} \varphi_j \Delta c_{t-m} + \delta_1 for_{t-1} + \delta_2 y_{t-1} + \delta_3 rf_{t-1} + \delta_4 c_{t-1} + \lambda_{10} \sin\left(\frac{2\pi nt}{T}\right) + \lambda_{11} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t. \tag{6}$$

Model 2 is stated as,

$$\Delta co_t = \varphi_i + \sum_{j=1}^{p} \lambda_j \Delta co_{t-j} + \sum_{i=0}^{n-1} \mu_i \Delta y_{t-i} + \sum_{k=0}^{z-1} \mu_k \Delta rf_{t-k} + \sum_{m=0}^{k-1} \varphi_j \Delta c_{t-m} + \delta_1 co_{t-1} + \delta_2 y_{t-1} + \delta_3 rf_{t-1} + \delta_4 c_{t-1} + \lambda_{20} \sin\left(\frac{2\pi nt}{T}\right) + \lambda_{21} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t. \tag{7}$$

the ECM representation of **Model 1** is obtained as,

$$\Delta for_t = \varphi_i + \sum_{j=1}^{p} \lambda_j \Delta for_{t-j} + \sum_{i=0}^{n-1} \mu_i \Delta y_{t-i} + \sum_{k=0}^{z-1} \mu_k \Delta rf_{t-k} + \sum_{m=0}^{k-1} \varphi_j \Delta c_{t-m} + \vartheta_1 (for_{t-1} - \varphi_1 y_{t-1} - \varphi_2 rf - \varphi_3 c_{t-1}) + \lambda_{10} \sin\left(\frac{2\pi nt}{T}\right) + \lambda_{11} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t. \tag{8}$$

and one's of **Model 2** is obtained as,

$$\Delta co_t = \varphi_i + \sum_{j=1}^{p} \lambda_j \Delta co_{t-j} + \sum_{i=0}^{n-1} \mu_i \Delta y_{t-i} + \sum_{k=0}^{z-1} \mu_k \Delta rf_{t-k} + \sum_{m=0}^{k-1} \varphi_j \Delta c_{t-m} + \vartheta_1 (\mathrm{co}_{t-1} - \varphi_1 y_{t-1} - \varphi_2 rf - \varphi_3 c_{t-1}) + \lambda_{20} \sin\left(\frac{2\pi nt}{T}\right) + \lambda_{21} \cos\left(\frac{2\pi nt}{T}\right) + \varepsilon_t. \tag{9}$$

the inclusion of two Fourier terms γ_{10} and γ_{11} in Model 1 and γ_{20} and γ_{21} in Model 2 aim at capturing the structural changes and nonlinearities. In Model 1, the Fourier terms are tested with the null hypothesis $H_0 : \lambda_{10} = 0, \lambda_{11} = 0$ against the alternative $H_1 : \lambda_{10} \neq 0, \lambda_{11} \neq 0$ and the calculated *F, Fourier* test statistic follows an *F* distribution. For simplicity, we follow [85] and assume the dimension of the Fourier function as $k = 1$.

4. Data

Annual data on traditional energy(firewood, charcoal, and coal)

consumption(hereafter energy consumption; c), refugee population(rf), deforestation(for), CO_2 emissions(co), and economic growth (y) were employed during the 1985–2020 period. Deforestation data are measured from forestation area (100- forestation (forestation is % of forest area in land area)). If the rate is increasing, there is deforestation; on the contrary, if it is decreasing, there is an increase in forest rates. CO_2 emissions was taken as proxies for environmental pollution. Economic growth was measured in Real GDP in constant 2005 USD. Deforestation, economic growth, and energy consumption data were obtained from the World Bank and UNDP. Traditional energy consumption data was measured as the sum of firewood, charcoal, and coal and obtained from country statistics and World Bank. To minimize skewness, the variables were logged (ln), and so they were measured in logarithms.

Table 1 previde descriptive statistics and corelations among the variables. The kurtosis statistics suggest no excess kurtosis. The skewness statistics for all variables suggest deviation from the expected value in the normal distribution and the findings reveal that the non-normal distribution of the variables is more likely the result of skewed distributional properties. The Jarque-Bera (JB) test tests the null of normally distributed series against the alternative of non-normality. The JB test results suggest the null of normality is rejected at the conventional significance levels for the majority of the variables analyzed

After [86–93] a few articles investigated the relationships between CO_2 emissions, energy use, and indicators of living standards. Many papers discovered significant links between energy use and living standards and high coefficients between a nation's traditional energy consumption and its Human Development Index (HDI). We will not use HDI variable as additional or control variable because some studies have found a high correlation coefficient between HDI and economic development. We also investigated this correlation in this study. Correlation coefficients were determined as 0.753, 0.71, and 0.69 for Ethiopia, Sudan and Uganda, respectively. Based on the results, since a high correlation was obtained between HDI and Y, it was decided to use the Y variable and evaluate the results for development and growth since using two variables at the same time would cause statistical errors.

In Table 1, we explaned corelations among the variables. It is important that the correlation coefficient is high for some variables.

Table 2
F-NL and FADF results.

	Uganda		Ethiopia		Sudan	
	FADF	NL(F–t_{NL})	FADF	NL(F–t_{NL})	FADF	NL(F–t_{NL})
c	−0.365	−0.289	−0.21	−0.18	−1.36	−1.29
Y	−0.778	−0.527	0.11	−0.563	−0.995	−0.845
rf	0.007	0.05	−1.76	−1.68	−0.88	−0.79
for	−0.776	−0.708	−0.15	−0.041	−0.66	−0.51
co	−1.861	−0.975	−0.765	−1.14	−0.912	−0.889
First Difference						
dc	−4.689	−4.697	−4.985	−3.91	−6.42	−5.86
dY	−5.774	−5.36	−4.985	−3.96	−5.824	−4.698
drf	−5.542	−4.8912	−5.07	−4.96	−6.28	−4.964
dfor	−5.25	−4.97	−5.11	−4.976	−5.778	−4.998
dco	−5.287	−4.685	−5.25	−4.74	−5.36	−4.985

Table 1
Descriptive statistics and correlation results.

Descriptive Statistics						
	C	CO	Y	RF	FOR	
Ethiopiarowhead						
Mean	2.685013	1.140272	10.25154	5.441857	1.125031	
Maximum	2.696418	1.837872	10.92611	5.955796	1.179379	
Skewness	0.315899	0.515201	0.575288	−0.026736	0.424242	
Kurtosis	2.062672	2.324814	1.810658	1.782402	1.734010	
Jarque-Bera	1.543949	1.833769	3.308850	1.794862	2.806542	
Sudanrowhead						
Mean	2.584524	0.647407	10.42320	5.527270	1.125031	
Maximum	2.619484	1.060358	11.09009	6.032734	1.179379	
Skewness	−0.023428	−0.413136	0.211442	0.211055	0.424242	
Kurtosis	2.644782	1.813943	1.519141	1.779932	1.734010	
Jarque-Bera	0.155120	2.524760	2.865896	2.013979	2.806542	
Ugandarowhead						
Mean	2.229352	0.109974	9.987294	5.411551	1.208022	
Maximum	2.411629	0.788835	10.43897	6.130493	1.376168	
Skewness	0.262388	0.103865	0.088669	1.596313	−0.643829	
Kurtosis	1.734459	1.575583	1.632798	2.974854	2.255265	
Jarque-Bera	2.268024	2.503805	2.296668	7.02893	2.673668	
Correlation Resultsrowhead						
Ethiopiarowhead						
	for	rf	co	Y		c
for	1					
rf	0.589	1				
co	0.7651	0.676	1			
y	0.759	0.439	0.8467	1		
c	0.86549	0.7099	0.749164	0.91894		1
Sudanrowhead						
	for	rf	co	Y		c
for	1					
rf	0.743	1				
co	0.963	0.576	1			
y	0.9502	0.439	0.7964	1		
c	0.521	0.59024	0.749164	0.59163		1
Ugandarowhead						
	for	rf	co	Y		c
for	1					
rf	0.534967	1				
co	0.578592	0.631082	1			
y	0.598604	0.8739	0.6623	1		
c	−0.5307	0.8554	−0.40126	0.90526		1

The correlation coefficients between refugees and deforestation and between refugees CO2 emissions exhibit high values. The correlation rates of the variables with each other provide preliminary information about the evidence of cointegration and causality. Since the correlation coefficients are high, we expect evidence of cointegration and at least unidirectional causality among the variables.

Before estimating a standard time series model, FADF (Fourier Augmented Dickey-Fuller) and NL(F–tNL) unit root tests are routinely conducted in Table 2. Especially in the case of structural breaks in the data, traditional unit root tests have low power to reject the H0 hypothesis. Moreover, ignoring the possible existence of gradual and multiple structural breaks in the data can lead to erroneous rejection of the null hypothesis of a unit root. Unit root test with Fourier can eliminate these states. The unit root tests with the Fourier method determined the variables as stationary at first differences. There is statistically strong evidence of the stationarity of the selected variables. It is observed that the shocks to variables have a transitory effect.

5. Results

Accordingly the results in Tables 3 and 4, we determined our models.

In Table 3, the results of FBARDL models were exhibited. If the BARDL or ARDL tests are used, it would be necessary to use a dummy variable because of crisis periods, but the FBARDL method eliminates this requirement.

When economic growth and/or refugee population are accepted as dependent variables, there is robust evidence in favor of the nonexistence of a long-run relationship between the refugee population, deforestation, energy consumption, and economic growth in Ethiopia, Sudan, and Uganda. But when traditional energy consumption is accepted as the dependent variable in Ethiopia, Uganda, and Sudan, it is obtained the states of degenerate-1, degenerate-1, and no-cointegration, respectively. And lastly, when deforestation is accepted as a dependent variable, there is robust evidence in favor of the evidence of a long-run relationship between the refugee population, deforestation, energy consumption, and economic growth in Ethiopia, Sudan, and Uganda.

And the results of the second model were given in Table 4.

In Ethiopia, Sudan, and Uganda, when economic growth is accepted as a dependent variable, the results of degenerate-1, nocointegration, and degenerate-2 for a long-run relationship between the refugee population, CO_2 emissions, energy consumption, and economic growth were determined. The refugee population is accepted as a dependent variable; there is robust evidence of the results of degenerate-1 and no-cointegration between the refugee population, CO_2 emissions, energy consumption, and economic growth in Ethiopia, Sudan, and Uganda, respectively. When CO_2 emissions are accepted as dependent variables, the evidence of cointegration between the refugee population, CO_2 emissions, energy consumption, and economic growth was determined.

In both models, the inclusion of two Fourier terms and in Model 1 and Model 2 aim at capturing the structural changes and nonlinearities. In Models, the Fourier terms are tested with the null hypothesis against the alternative and the calculated F, Fourier test statistic follows an F distribution with q, and (n-h-1) degrees of freedom under the null where n is the sample size and h is the total number of parameters in the model estimated. As mentioned above, we follow [85] and assume the dimension of the Fourier function as $k = 1$. As a result, $q = 2$ in the F, Fourier test in our study. For more complex nonlinear forms, increasing the dimension could be considered. This will necessitate testing the number of parameters where k is the number of dimensions under the null, which increases the loss of degrees of freedom drastically, and for the majority of applications, a single Fourier dimension would be satisfactory [83,85]. The cointegration among the selected variables requires the rejection of three null hypothesis.

5.1. Long-run and short-run coefficients and ECM

For Model 1, when deforestation is accepted as the dependent variable, long and short-run coefficients, and ECM coefficients are shown in Table 5.

We used Fourier terms with two frequencies. If the Fourier frequency increases and the test has less size distortion. In Table 4, for Ethiopia, Uganda, and Sudan, refugees' effects on deforestation were determined as 0.28, 0.218, and 0.23, and the effect of traditional energy consumption was found as 0.315, 0.318, and 0.28. The impact of conventional energy consumption on deforestation is very significant. A 1% increase in conventional energy consumption increases deforestation by 3.15%, 3.18%, and 3%, respectively. These results are consistent with the correlation results between the variables.

In Table 6, for Ethiopia, Uganda, and Sudan, a 1% increase in refugees population increases CO2 emissions by 2.02%, 2.27%, and 2.05% in the long run, and in the short-run, the coefficients change as 0.19, 0.277, and 0.183, respectively. The coefficients of traditional energy consumption were found as 0.167, 0. 163, and 0.1856 in the long-run and 2.6%, 4.39%, and 1.52% in the short-run.

The coefficients of emc are −0.28, −0.13, and −0.19 for Ethiopia, Uganda, and Sudan respectively.

5.2. The results of granger causality

Table 7 exhibits the results for Model 1. According to the Granger causality test results, a unidirectional causality running from the refugee population to deforestation was found for Sudan, Uganda, and Ethiopia. We found the evidence of unidirectional causality running from traditional energy consumption to deforestation and evidence of unidirectional causality running from the refugee population to energy consumption. That is, traditional energy consumption is the Granger cause of deforestation, and the refugee population is the Granger cause of traditional energy consumption and deforestation.

For the direction of causality between refugees population and economic growth, it was obtained different result. For Ethiopia, it was determined evidence of unidirectional causality running from refugees population to economic growth, but for Sudan and Uganda, it was

Table 3
Fourier bootstrapping ARDL for model 1.

Country	Dependent Var/Independent Var	F	F*	Findep	F*indep	t	T*	Cointegration Status
Ethiopia	(y/rf,for,c)	2.356	4.85	5.256	7.012	−1.36	−1.968	No-Cointegration
	(rf/for,y,c)	4.256	5.557	3.856	4.12	−1.56	−3.885	No-Cointegration
	(for/y, rf,c)	10.26	8.25	11.2	10.086	−4.03	−3.856	Cointegration
	(c/y,for,rf)	8.568	8.258	3.85	4.14	−5.25	−3.856	Degenerate 1
Uganda	(Y/rf,for,c)	3.856	4.001	3.88	3.95	−3.15	−4.256	No-Cointegration
	(rf/for,y,c)	1.045	2.856	3.256	4.856	−1.08	−2.856	No-Cointegration
	(for/y, rf,c)	10.56	9.056	7.73	6.64	−5.06	−4.896	Cointegration
	(c/y,for,rf)	8.425	8.256	4.256	4.596	−4.59	−7.145	Degenerate-1
Sudan	(Y/rf,for,c)	4.25	5.60	2.83	3.67	−2.07	−3.93	No-Cointegration
	(rf/for,y,c)	2.33	3.92	2.17	4.6	−0.10	−0.11	No-Cointegration
	(for/y, rf,c)	14.03	13.22	12.78	11.24	−8.02	−7.11	Cointegration
	(c/y,for,rf)	1.256	2.589	2.589	3.589	−2.12	−3.485	No-Cointegration

Table 4
Fourier bootstrapping ARDL for model 2.

Country	Dependent Var/Independent Var	F	F*	Findep	F*indep	t	T*	Cointegration Status
Ethiopia	(c/rf, y, co)	2.12	3.86	3.56	5.48	−1.16	−3.052	No-Cointegration
	(rf/y,c, co)	9.87	9.11	3.12	3.65	−6.51	−3.26	Degenerate 1
	(co/y, rf, c)	11.16	10.2	10.05	9.16	−5.11	−4.56	Cointegration
	(y/co, rf, c)	9.18	9.01	3.21	3.99	−5.99	−4.12	Degenerate 1
Uganda	(c/rf, y, co)	4.11	3.961	4.491	3.66	−3.14	−4.88	Degenerate-2
	(rf/y,c, co)	1.316	2.919	2.126	3.856	−1.98	−2.45	No-Cointegration
	(co/y, rf, c)	8.87	7.116	7.89	6.98	−5.15	−4.16	Cointeration
	(y/co, rf, c)	9.35	8.96	5.23	4.29	−4.99	−7.55	Degenerate-2
Sudan	(c/rf, y, co)	6.33	5.29	2.41	4.68	−4.31	−3.72	Degenerate 1
	(rf/y,c, co)	2.11	3.64	2.37	4.12	−0.56	−0.57	No-Cointegration
	(co/y, rf, c)	14.46	13.86	12.55	11.07	−8.96	−7.47	Cointegration
	(y/co, rf, c)	2.86	2.99	1.19	3.14	−2.44	−3.99	No-Cointegration

Table 5
Long Run Coefficients and ECM term for Model 1+.

	Ethiopia	Uganda	Sudan
Dependent variable:deforestation			
ly	−0.28(2.19)**	−0.24(1.96)*	−0.22(1.9)*
lrf	0.28(1.87)*	0.218(1.99)**	0.23(1.93)*
lc	0.315(1.78)*	0.318(1.99)**	0.28(2.07)**
dy	0.247(2.31)**	0.316(2.698)***	0.245(2.45)**
drf	0.311(2.62)***	0.317(1.95)**	0.299(2.27)**
dc	0.223(1.91)*	0.338(2.81)***	0.36(1.84)*
ecm	−0.25(1.83)*	−0.29(2.22)**	−0.27(1.92)*
F1	0.0005(1.88)*	−0.00025(1.98)**	0.0003 (1.79)*
F2	−0.00092(1.76)*	0.00041 (1.83)*	0.00027 (2.01)**
R^2	0.77	0.75	0.76
Jarque–Bera	2.8	2.7	2.44
Ramsey RESET	0.5	0.48	0.31
ARCH method	0.87	0.83	0.76
Q-statistics	0.99	0.99	0.90

+(…) shows t value. Notes. *, **, ** indicate that parameters are statistically significant at 10%, 5% and 1%, respectively. *t* statistics are in parentheses. d is the difference operator. *F, Fouriers* is the F test with F(q, n-q-1) degrees of freedom where that tests the null hypothesis of two Fourier parameters = 0; (i.e. q = 2).

Table 6
The Coefficients and ECM term for Model 2+.

	Ethiopia	Uganda	Sudan
Dependent variable: CO_2 emissions			
lc	0.167810(4.72)***	0.163354(3.03646)***	0.1856(2.46)**
lrf	0.202319(1.97)**	0.22720(2.987531)***	0.2048(2.15)**
ly	0.632497(2.022)**	0.4586(6.02698)***	0.371495(2.78)***
dc	0.26111(2.45)**	0.239197(1.9865)**	0.152889(7.27)***
drf	0.190023(1.75)*	0.277622(3.003)***	0.183736(1.766)*
dy	−0.492133 (-2.022)**	−0.303657(-8.439)***	0.033577(1.82)*
ecm	−0.287(2.44)**	−0.135315(2.1853)**	−0.191422(2.53)***
F1	−0.00094(4.81)***	0.0001314(2.36)**	0.000630(1.92)**
F2	−0.000722(1.95)**	0.00047(2.08)**	0.00017(1.94)*
R^2	0.71	0.68	0.73
Jarque–Bera	3.01	3.23	2.46
Ramsey RESET	0.25	0.31	0.36
ARCH method	0.91	0.93	0.7
Q-statistics	1.1	1.1	0.91

+(…) shows t value. Notes. *, **, ** indicate that parameters are statistically significant at 10%, 5% and 1%, respectively. *t* statistics are in parentheses. d is the difference operator. *F, Fouriers* is the F test with F(q, n-q-1) degrees of freedom where that tests the null hypothesis of two Fourier parameters = 0; (i.e. q = 2).

determined the evidence of unidirectional causality running from economic growth to refugees population. Granger causality results are given in Fig. 1.

→Show direction of causality.

InTable 8, the result of unidirectional causality from the refugee population, and traditional energy consumption to CO_2 emissions were determined. As a brief for all countries, it was determined the evidence of unidirectional causality running.

1 from the refugee population to energy consumption
2 from the refugee population to CO_2 emissions
3 from energy consumption to CO_2 emissions
4 from energy consumption to economic growth and lastly it was determine none causality between economic growth and refugees population

Fig. 2. Presents the results of Granger causality for Model 2.

6. Discussion

The results determined the existence of unidirectional causality from the refugee population to deforestation and CO_2 emissions, unidirectional causality from refugees population to traditional energy consumption and unidirectional causality from traditional energy consumption to deforestation and CO_2 emissions. The refugee population is granger cause of deforestation, CO_2 emissions, and energy consumption, and the energy consumption is the Granger causality of CO_2 emissions and deforestation The refugees that cause to rise in energy consumption lead to increasing CO_2 emissions. Energy consumption is not only the Granger cause of environmental pollution, but also energy consumption is the Granger cause of economic growth. A decline in energy consumption can have positive effect on the environmental pollution but it will have adverse effects on economic growth.

The refugee population has a significant impact on the increase in energy consumption an increased population means increased energy needs. Refugees in these countries undoubtedly have a significant impact on this result, as this figure is quite large. Although developing countries host 86% of their refugees, the refugee crisis is a global problem. During the 2009–2018 period, the amount of forcibly displaced individuals rose from 43.3 million to 70.8 million [2].

84% of refugees today were housed in developing nations, compared to 16% in developed nations. Three nations accounted for more than 57% of all refugees: South Sudan (2.3 million(M)), Afghanistan (2.7 M), and Syria (6.7 M). Pakistan (1.4 M), Sudan (1.1 M), and Uganda (1.2 M) also host refugees [94]. The number of immigrants worldwide increased by around 244 million in 2015, reaching 3% of the global population,

Table 7
Causality results for model 1.

Direction of causality					
Δ y→ Δ for Δ for→ Δ y	Δ rf → Δ for Δ for→ Δ rf	Δ c→ Δ rf Δ rf→ Δ c	Δ c→ Δ for Δ for→ Δ c	Δ rf→ Δ y Δ y→ Δ rf	Δ c→ Δ y Δ y→ Δ c
Ethiopia					
5.821	3.15	0.016	8.319	4.64	5.851
1.19	0.533	7.668	0.845	0.86	0.65
Unidirectional y→for	rf→for	Unidirectional rf→c	Unidirectional c→for	Unidirectional rf→y	Unidirectional c→y
Sudan					
8.366	4.48	1.78	4.68	1.66	9.12
0.731	0.11	8.91	0.47	5.36	1.77
Unidirectional y→for	Unidirectional rf→for	Unidirectional rf→c	Unidirectional c→for	Unidirectional y→rf	Unidirectional c→y
Uganda					
5.062	31.39	1.317	8.61	1.036	5.657
1.58	1.16	5.81	0.12	6.12	1.17
Unidirectional y→for	Unidirectional rf→for	Unidirectional rf→c	Unidirectional c→for	Unidirectional y→rf	Unidirectional c→y

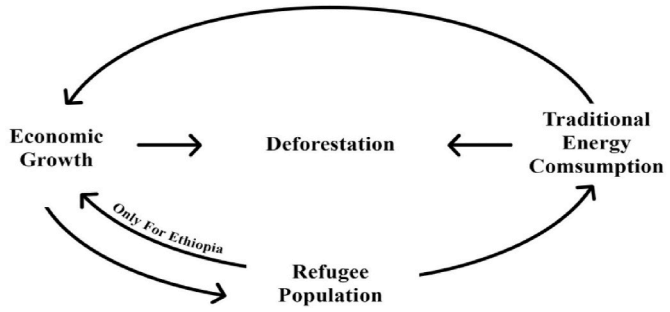


Fig. 1. Casuality results for model 1.

with over 65 million people leaving Syria, Afghanistan, and Somalia [95]. The number of newly displaced people in 2018 was 13.6 million [2]. In 2021, the rate is even higher. Fig. 3 shows this situation.

Fig. 3 shows the distribution of the refugee population throughout the world (UNHCR data was used).

The countries analyzed are those with the highest number of refugees.

As seen in Fig. 4, the share of the total asylum-seeking population in the total population over the years is constantly increasing in Sudan and Uganda.

(Calculated from the WB data: we calculated the total number of refugees over the years based on the World Bank data and found the ratio of this to the population).

When the period between 1985 and 2020 in Sudan is examined, it is seen that it approached 1% of the total population in 2020. It should be noted that our calculations cover after 1985 and not before.

Fig. 5, on the other hand, shows the proportion of the refugee population arriving each year in the total population. Although the number of refugees between 1985 and 1990 was very high compared to other years, the rate of refugees in 2020 was 0.04 of the total population. This is a very high rate. This population usually settles in these regions. In these countries, they settle in areas close to the border. Moreover, the host population living in areas close to the border in these countries is traditionally energy dependent, as is the case with refugees. Refugees increase traditional energy dependence, and forest areasin these regions.

(Calculated from the WB data and UNHCR data).

Forest areas the countries have been declining for the past few years due to human activity. This issue should also be examined in the context of rising firewood, charcoal, and coal consumption, house construction, the bartering or selling of food in exchange for firewood [12], and the clearing of agricultural land.

Especially the distribution of forest areas in Sudan, Ethiopia, and Uganda is observed clearly in Fig. 6 and Fig. 7.

Fig. 6 exhibits the natural forest and net loss of forest area (data was taken from FAO and WB). In Fig. 7, forest area was exhibited as % of land area between 1990 and 2018. As seen from the figures, deforestation is

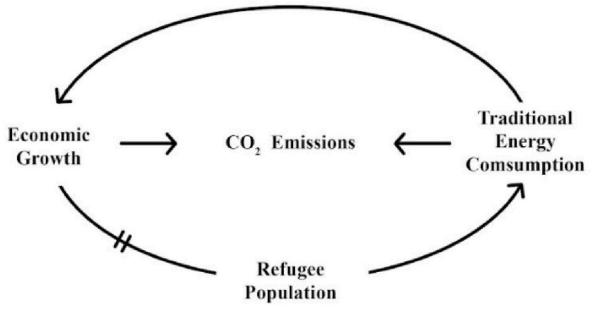


Fig. 2. Casuality results for model 2.

Table 8
Causality results for model 2.

Δ *Y*→ Δ *rf* Δ *rf*→ Δ *Y*	Δ *Y* → Δ *Co* Δ *Co*→ Δ *Y*	Δ c→ Δ y Δ y→ Δ c	Δ *rf*→ Δ *c* Δ *c*→ Δ *rf*	Δ *C o*→ Δ *r* Δ *rf*→ Δ *Co*	Δ *c*→ Δ *co* Δ *co*→ Δ *c*
Ethiopia					
1.46	4.32	6.46	11.78	1.074	9.41
1.64	0.31	0.042	0.67	8.74	0.038
None	Unidirectional *y*→*Co*	Unidirectional c→y	Unidirectional *rf*→*c*	Unidirectional *rf*→*Co*	Unidirectional *C*→Co
Sudan					
0.435	*6.290*	*3.216*	5.348	1.467	9.405
1.032	*0.053*	*1.415*	0.578	7.602	1.43
None	Unidirectional *y*→*Co*	Unidirectional c→y	Unidirectional *rf*→*c*	Unidirectional *rf*→*Co*	Unidirectional *C*→Co
Uganda					
0.522	8.036	6.07	7.063	1.35	8.32
0.221	0.91	0.13	0.205	6.18	0.12
None	Unidirectional *y*→*Co*	Unidirectional c→y	Unidirectional *rf*→*c*	Unidirectional *rf*→*Co*	Unidirectional *C*→Co

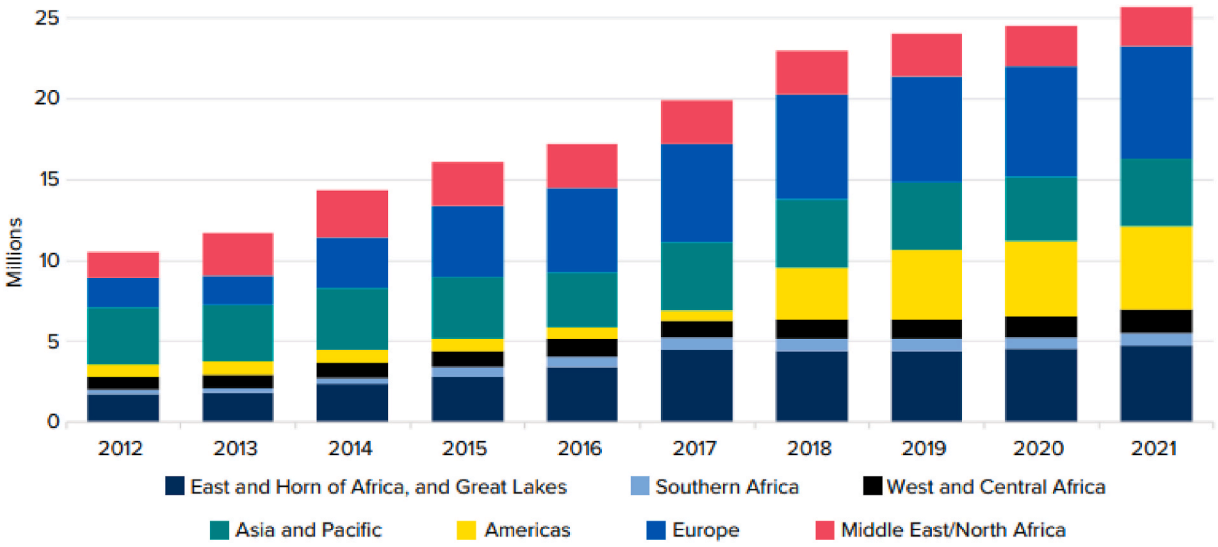


Fig. 3. Distribution of refugee population.

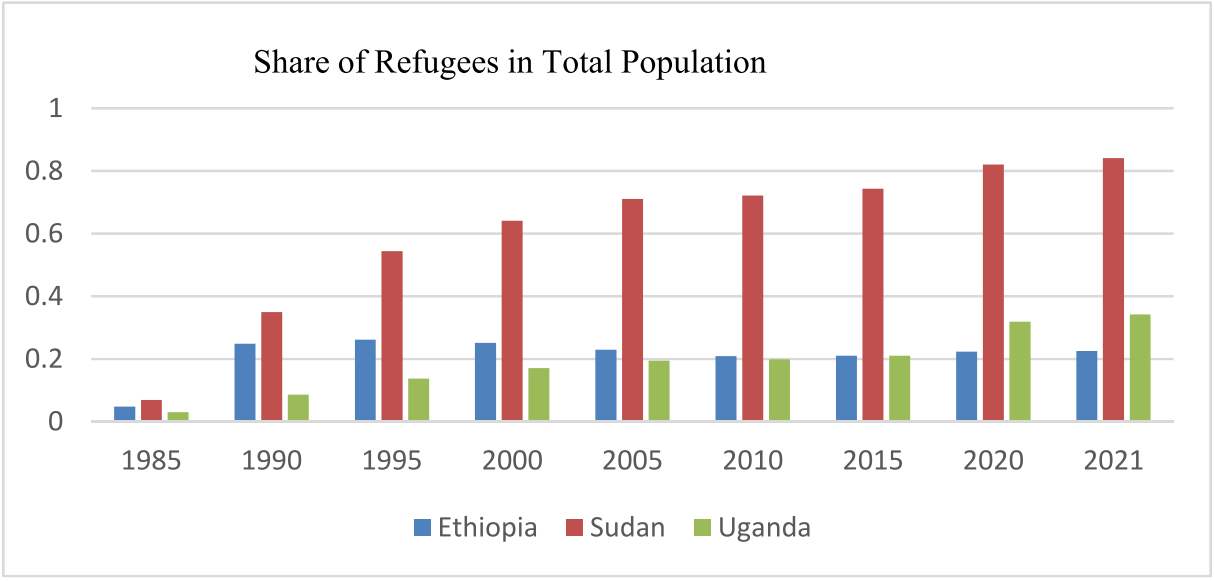


Fig. 4. Share of total refugees in total population.

high in these countries. For example, Ethiopia is an agricultural nation with little forest land in the context of the nations chosen for this paper. Due to the rapid destruction, the native forest is diminishing. For example between 2003 and 2008, 2 million Sudanese refugees in Darfur consumed 1500 tons of wood daily (See Ref. [12] for barter). Although Uganda is the most humid and moist country in the subregion, forest areas quickly decline [2]. The cutting down of millions of trees has sparked angry clashes in parts of Uganda between local people and refugees [3] who have been fleeing conflict in neighboring South Sudan and the Democratic Republic of the Congo. Since the timber is being used for house construction, fuel, and to make charcoal, in the north and west of the country, where an estimated 1.1 million refugees are living, massive deforestation is drawing protests from local communities.

Some studies found similar results to our results. [2] showed that the settling of refugees was causing widespread environmental damage. A refugee cuts [down] around 20 trees per year. [Locals] see their own environment being depleted increasingly.

Some papers discussed the effect of timber sueage on deforestation [82]. showed that deforestation could emerge due to logging activities to provide woody biomass as the alternative source of fuel energy, such as kerosene and cooking gas, or electricity (See for woody biomass [96]). According to Ref. [97], forests in poorer strict are cleared more rapidly than others. As a result [81] showed that in developing countries, the rapid rise in population is a primary cause of deforestation that continues. According to Ref. [37], in Latin American, Asian, and African countries, the growth rate of the population increases the transformation of forests for arable land because the primary purpose of the majority of people living in rural areas is to survive, and this mostly depends on agriculture.

On the other hand as mentioned above, traditional energy usage is the most important factor in carbon dioxide emissions.

Effects of refugees in these countries on deforestation and environmental pollution can be explained in a number of ways. The firstly, when refugees settle in new areas, they may clear forests for agriculture, firewood, and building materials. This can increase pressure on natural resources and lead to deforestation. Additionally, if refugees are using traditional cooking methods, such as charcoal made from burning wood, this can further exacerbate deforestation and contribute to

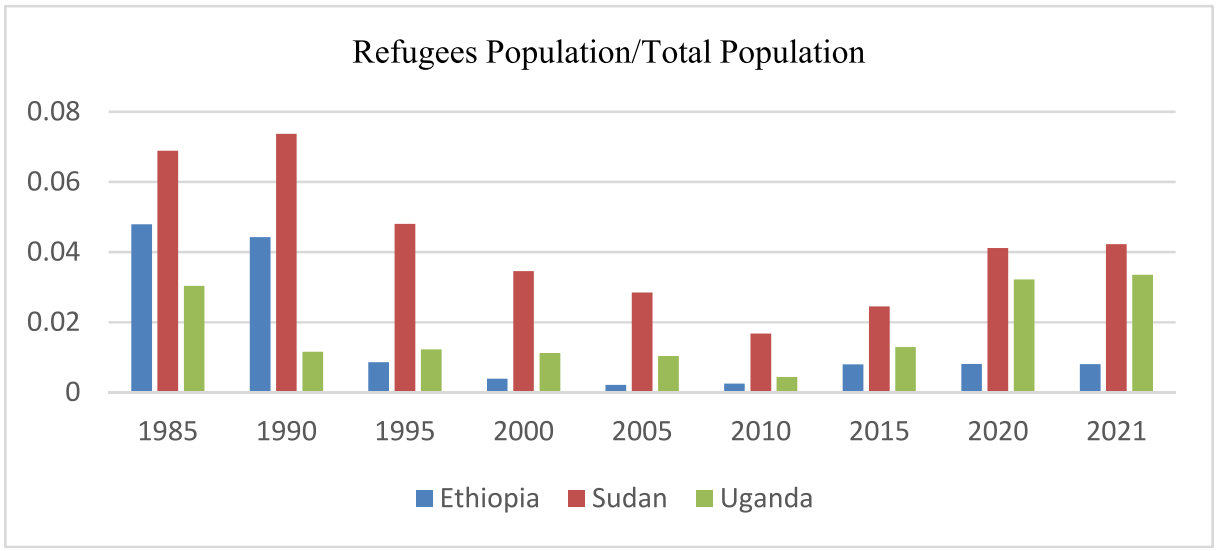


Fig. 5. The share of refugees in the population every year.

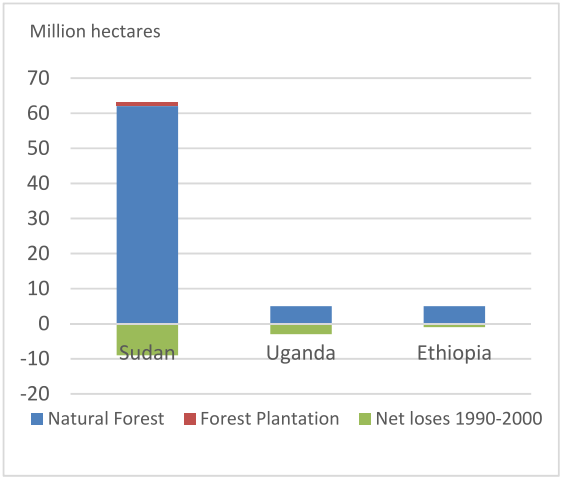


Fig. 6. Forest area from 1990 to 2000

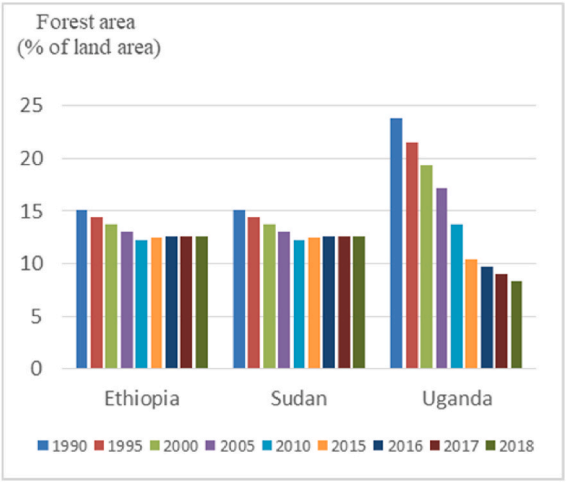


Fig. 7. Deforestation between 1990 and 2018 years.

environmental pollution. The burning of charcoal can also release harmful pollutants into the air, contributing to air pollution and having negative impacts on human health. To promote sustainability and reduce environmental pollution, it's important to explore alternative energy sources and implement measures to prevent excessive deforestation. This can include promoting the use of cleaner-burning fuels, increasing access to electricity, and encouraging the use of efficient cookstoves. According to Ref. [98], deforestation is directly related to economic development and energy usage. As mentioned in the introduction section, because forests are used for house construction and barter, achieving economic development can reduce dependence on timber in these regions.

Finally, it should be emphasized that the situation of these countries cannot be explained by the EKC hypothesis, which is widely used in the context of environmental pollution. This hypothesis suggests that in the initial phase of economic development there will be environmental degradation, but after reaching a certain level of economic growth, society will start to improve its relationship with the environment and the levels of environmental degradation will decrease. As emphasized above, the danger for these countries is not only environmental degradation but also the depletion of their natural resources. Refugees, as explained above, could lead to a more rapid depletion of these natural resources. This would lead to lower income levels for the people who depend on these natural resources for their livelihoods.

7. Conclusion, policy implications and limitations

This study aimed to analyze the cointegration and Granger causality between traditional energy consumption, refugee population, environmental pollution, deforestation, and economic growth. The effects of the refugee population on deforestation and environmental pollution for the period 1985–2020 were analyzed by the Fourier unit root test, Fourier BARDL, and Fourier Granger causality methods in Sudan, Uganda, and Ethiopia with two different models. The first model gave us the effect of refugees, energy consumption and economic growth on deforestation. The second model investigated the impact of refugee, conventional energy consumption and economic growth on CO_2 emissions. The first model determined the existence of unidirectional causality from the refugee population to deforestation and from traditional energy consumption to deforestation. In the second model, the existence of unidirectional causality from the refugee population to CO_2 emissions, and traditional energy consumption and from traditional energy consumption to CO_2 emissions. Both models determined the evidence of

unidirectional causality from the refugee population to traditional energy consumption.

The policymakers of the countries must determine their policies accordingly and their characteristics. For the host countries, the continuing migration movements generate problems in the context of deforestation and environmental pollution in addition to social, economic as well as health-linked problems. The burden of refugees necessitates improved coordination. Better coordination is required to address the issues brought on by the growing refugee population. Thus, decision-makers must be able to discuss the factors that influence the energy needs of the expanding refugee population, the issues that these people bring, and their effects on deforestation, environmental degradation, and natural resources. At the same time, refugees often live in overcrowded and poorly managed settlements, which can result in the generation of solid waste, sewage, and other forms of pollution.

It is main for policymakers to deliberate the dynamics of the refugee population that will have a long-term impact on residential energy demand in the cities. Because it is important to consider alternative, sustainable energy sources and to implement measures to prevent excessive deforestation in areas affected by refugee crises. The energy demand of the refugee population can be accomplished with the use of renewable energy. Renewable energy, especially solar energy (see for renewable [99,100]), may provide cost-effective and reliable energy to the refugees. The consumption of renewable energy resources will reduce adverse environmental impacts and support air quality. Moreover, using renewable energy in the refugee camps in these countries is a method of protecting the environment and trees.

Renewable energy sources can be used to meet the refugee population's energy needs for deforestation and environmental damage. Natural resources and renewable energy are abundant in these countries. Additionally, these countries do not utilize natural resources to their greatest potential. To this end, solar energy, in particular, can produce reliable and economical electricity. Utilizing renewable energy sources to meet energy demands could promote sustainable development by minimizing adverse environmental effects.

And to promote sustainability and reduce environmental pollution in the context of refugee populations, it's important to consider the root causes of displacement and address them. This can include efforts to mitigate the impacts of climate change, address political instability, and promote peace and security. Additionally, it's important to implement measures to prevent environmental degradation and pollution in refugee settlements, such as proper waste management and access to clean water and energy. Income transfers may reduce demand for forest products in the event that substitution between forest and non-forest goods is feasible [93]. But refugees face severe income constraints, and substitutes for cooking fuel, such as liquid propane gas cookstoves, may not be available in the markets they can access [7]. By prioritizing sustainability, we can improve the lives of refugees and protect the environment. As highlighted by Refs. [51,52,77], offering microcredit together with skill development training for occupations like basket making, weaving, and tailoring can make the refugees self-reliant in terms of earning money. The policies governing the size and placement of the refugee camps need to be modified on a macro level. More minor, dispersed camps have less of an impact on deforestation than bigger, more concentrated ones.

Another important government policy is reforestation. Deforestation, specifically, leads to the loss of habitat and resources, making it difficult for people to sustain their lives, thus leading to migration. Addressing deforestation through conservation and reforestation efforts can help to reduce the number of sustainability refugees and improve the lives of those affected.

The fact that the study limits the number of countries may seem like a deficiency, but the aim is to start this discussion. Expanding the next study to other recipient countries will allow the discussion to expand

Credit author statement

Melike E. Bildirici: Conceptualization, Methodology, Investigation, Data Curation, Visualization, Writing, **Rui Alexandre Castanho:** Funding acquisition, Resources, Writing - Original Draft, **Gualter Couto**: Funding acquisition, Data Curation, **Sema Yılmaz Genç**: Resources, Writing - Original Draft, Writing - Review & Editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sema Yilmaz Genc reports was provided by Yildiz Technical University. Sema Yilmaz Genc reports a relationship with Yildiz Technical University Faculty of Economics and Administration Science that includes: board membership, consulting or advisory, employment, equity or stocks, funding grants, non-financial support, paid expert testimony, speaking and lecture fees, and travel reimbursement. Sema Yilmaz Genc has patent pending to Assignee. None.

Data availability

The data that has been used is confidential.

References

[1] World Bank, Rapid Assessment of Natural Resource Degradation in Refugee, 2019.
[2] UNHCR, Global Trends Forced Displacement in 2018, 2019. https://www.unhcr.org/5d08d7ee7.pdf.
[3] The Guardian, Massive Deforestation by Refugees in Uganda Sparks Clashes with Local People, 2019.
[4] M. Bildirici, Refugees, Governance, and Sustainable Environment: PQARDL Method, Environmental Science and Pollution Research, 2022, pp. 39295–39309.
[5] M. Ru, S. Tao, K. Smith, G. Shen, H. Shen, Y. Huang, Direct energy consumption associated emissions by rural-to-urban migrants in Beijing, Environ. Sci. Technol. 49 (22) (2015) 13708–13715.
[6] K. Smith, G. Shuhua, H. Kun, Q. Daxiong, One hundred million improved cookstoves in China: how was it done? World Dev. 21 (6) (1993) 941–961.
[7] T. Nussbaumer, Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction, Energy Fuel. 17 (6) (2003) 1510–1521.
[8] M. Bizzarri, C. Bellamy, E. Patrick, C. Roth, Safe Access to Firewood and Alternative Energy in Uganda: an Appraisal Report, 2009.
[9] V. Ramanathan, G. Carmichael, Global and regional climate changes due to black carbon, Nat. Geosci. 1 (4) (2008) 221–227.
[10] X. Wang, D. Westerdahl, J. Hu, Y. Wu, H. Yin, X. Pan, K. Zhang, On-road diesel vehicle emission factors for nitrogen oxides and black carbon in two Chinese cities, Atmos. Environ. 14 (2012) 45–55.
[11] G. Lahn, O. Grafham, Heat, Light and Power for Refugees: Saving Lives, Reducing Costs, Chatham House Report for the Moving Energy Initiative, 2015.
[12] J. Barbieri, F. Riva, E. Colombo, Cooking in Refugee Camps and Informal Settlements: A Review of Available Technologies and Impacts on the Socio-Economic and Environmental Perspective, Sustainable Energy Technologies and Assessments, 2017, pp. 194–207.
[13] J. Lehne, W. Blyth, G. Lahn, M. Bazilian, O. Grafham, Energy services for refugees and displaced people, Energy Strategy Rev. 13 (2016) 134–146.
[14] UNHCR, UNHCR Turkey - Fact Sheet, 2019.
[15] IEA, Scaling-up the Transition to Electric Mobility, International Energy Agency, Paris, France, 2019.
[16] J. Dean, J. Middelburg, T. Röckmann, R. Aerts, L. Blauw, M. Egger, A.J. Dolman, Methane feedbacks to the global climate system in a warmer world, Rev. Geophys. 56 (1) (2018) 207–250.
[17] R. Herendeen, J. Tanaka, Energy cost of living, Energy 1 (2) (1976) 165–178.
[18] R. Ayres, A.V. Kneese, Production, consumption, and externalities, Am. Econ. Rev. 59 (3) (1969) 282–297.
[19] T. Malthus, An Essay on the Principle of Population as it Affects the Future Improvement of Society, Johnson, London, 1800.
[20] D. Christopoulos, M. León-Ledesma, Current account sustainability in the US: what did we really know about it? J. Int. Money Finance 29 (3) (2010) 442–459.
[21] M. Bildirici, F. Kayıkçı, The relation between growth, energy imports, militarization and current account balance in China, Israel and South Korea, Energy (2022), 122537.
[22] M. Bildirici, S. Lousada, S. Yılmaz Genç, Terrorism, freshwater, and environmental pollution: evidence of Afghanistan, Burkina Faso, Iraq, arab republic of Egypt, Cameroon, Mali, Mozambique, Niger, Nigeria, Water 14 (17) (2022) 2684.

[23] M. Bildirici, R. Castanho, F. Kayıkçı, S. Yılmaz Genç, ICT, energy intensity, and CO2 emission nexus, Energies 15 (13) (2022) 4567.
[24] G. Grossman ve A. Krueger, Environmental Impacts of the North American Free Trade Agreement, NBER. Working paper, 1991, p. 3914.
[25] G. Marsh, Man and Nature: or, Physical Geography as Modified by Human Action, Scribner, New York, 1864.
[26] K. Lindblade, J. Tumuhairwe, G. Carswell, C. Nkwiine, D. Bwamiki, More People, More Fallow: Environmentally Favorable Land-Use Changes in Southwestern Uganda, Report to the Rockefeller Foundation and CARE International, 1996.
[27] M. Tiffen, M. Mortimore, F. Gichuki, More People, Less Erosion: Environmental Recovery in Kenya, John Wiley & Sons Ltd, 1994.
[28] P. Ehrlich, The Population Bomb, Yale University Press, 1968.
[29] D. Meadows, D. Meadows, J. Randers, W. Behrens, The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind, Universe Books, New York, 1972.
[30] T. Panayotou, The population, environment, and development nexus, Population and development: Old debates, new conclusions (1994) 148–180.
[31] V. Lassailly-Jacob, The Environmental Impacts of Refugee Settlement: A Case Study of an Agricultural Camp in Zambia. In People and Their Planet, Palgrave Macmillan, London, 1999.
[32] U. Pascual, E. Barbier, Deprived land-use intensification in shifting cultivation: the population pressure hypothesis revisited, Agric. Econ. 34 (2) (2006) 155–165.
[33] J. Alix-Garcia, S. Walker, A. Bartlett, H. Onder, A. Sanghi, Do refugee camps help or hurt hosts? The case of Kakuma, Kenya, J. Dev. Econ. 130 (2018) 66–83.
[34] A. Foster, M. Rosenzweig, Economic growth and the rise of forests, Q. J. Econ. 118 (2) (2003) 601–637.
[35] C. Salemi, Refugee camps and deforestation in sub-saharan Africa, J. Dev. Econ. 152 (2021), 102682.
[36] J. Alix-Garcia, C. McIntosh, K. Sims, J.R. Welch, The ecological footprint of poverty alleviation: evidence from Mexico's Oportunidades program, Rev. Econ. Stat. 95 (2) (2013) 417–435.
[37] M. Cropper, C. Griffiths, The interaction of population growth and environmental quality, Am. Econ. Rev. 84 (2) (1994) 250–254.
[38] S. Scrieciu, Can economic causes of tropical deforestation be identified at a global level? Ecol. Econ. 62 (3–4) (2007) 603–612.
[39] H. Albers, E.J.Z. Robinson, A review of the spatial economics of non-timber forest product extraction: implications for policy, Ecol. Econ. 92 (2013) 87–95.
[40] D. Miteva, R. Kramer, Z. Brown, M. Smith, Spatial patterns of market participation and resource extraction: fuelwood collection in Northern Uganda, Am. J. Agric. Econ. 99 (4) (2017) 1008–1026.
[41] B. Boskovic, U. Chakravorty, M. Pelli, A. Risch, The Effect of Forest Access on the Market for Fuelwood in India, CESifo Working Paper, 2018.
[42] A. Betts, L. Bloom, J. Kaplan, N. Omata, Refugee Economies: Forced Displacement and Development, Oxford University Press, 2017.
[43] G. Qu, Population Control and Environment Protection, Renkou Yanjiu, 1982, pp. 43–48.
[44] A. Sherbinin, D. Carr, S. Cassels, L. Jiang, Population and environment, Annu. Rev. Environ. Resour. (2007) 345–373.
[45] H. Geist, E. Lambin, What drives tropical deforestation, LUCC Rep. Ser. 4 (2001).
[46] F. Meyerson, Toward a Per Capita-Based Climate Treaty: Reply, Population and Development Review, 1998, pp. 804–810.
[47] N. Allan, Impact of Afghan Refugees on the Vegetation Resources of Pakistan's Hindukush-Himalaya, Mountain Research and Development, 1987, pp. 200–204.
[48] R. Black, Forced migration and environmental change: the impact of refugees on host environments, J. Environ. Manag. 42 (3) (1994) 261–277.
[49] G. Shephard, The Impact of Refugees on the Environment and Appropriate Response, Forestry Program ODI, 1995.
[50] K. Ghimire, Refugees and deforestation, Int. Migrat. 32 (4) (1994) 561–570.
[51] K. Jacobsen, Refugees' environmental impact: the effect of patterns of settlement, J. Refug. Stud. 10 (1) (1997) 19–36.
[52] K. Jacobsen, The forgotten solution: local integration for refugees in developing countries, UNHCR New Issues in Refugee Research (2001).
[53] S. Dick, Review of CORD Community Services for Congolese Refugees in Tanzania, United Nations High Commissioner for Refugees, Geneva, 2002.
[54] UNHCR, Refugee Operations and Environmental Management: a Handbook of Selected Lessons Learned from the Field, 2002. Geneva.
[55] P. Otieno, D. Gazarwa, Joint Assessment Mission-Kenya Refugee Operation, 2014. Genova.
[56] E. Kalipeni, Population; Population growth and environmental degradation in Malawi, Afr. Insight 22 (4) (1992) 273–282.
[57] H. Ketel, Tanzania: Environmental Assessment Report of the Rwandese Refugee Camps and the Affected Local Communities in Kagera Region, PTSS Mission Report, 1994.
[58] A. Biswas, C. Quiroz, Environmental impacts of refugees: a case study, mpact Assessment 14 (1) (1996) 21–39.
[59] J. Maystadt, V. Mueller, J. Van Den Hoek, S. Van Weezel, Vegetation changes attributable to refugees in Africa coincide with agricultural deforestation, Environ. Res. Lett. 15 (4) (2020).
[60] N. Allan, Impact of Afghan Refugees on the Vegetation Resources of Pakistan's Hindukush-Himalaya, Mountain Research and Development, 1987, pp. 200–204.
[61] N. Allan, Deforestation et agropastoralisme dans le Pakistan du Nord, Rev. Géogr. Alp. 74 (4) (1986) 405–420.
[62] A. Braun, S. Lang, V. Hochschild, Impact of refugee camps on their environment a case study using multi-temporal SAR data, Journal of Geography, Environment and Earth Science International 4 (2) (2016) 1–17.
[63] A. Braun, V. Hochschild, A SAR-based index for landscape changes in African savannas, Rem. Sens. 9 (4) (2017) 359.
[64] A. Harper, A Critical Time for Refugees and Their Environment (Again), UNHCR Innovation, 2016.
[65] S. Labib, N. Hossain, S. Patwary, Environmental Cost of Refugee Crisis: Case Study of Kutupalong Balukhali Rohingya Camp Site a Remote Sensing approach., in Proceedings of the 26th Annual GIScience Research UK, GISRUK 2018, Leicester, UK, 2018.
[66] M. Hassan, A. Smith, K. Walker, M. Rahman, J. Southworth, Rohingya refugee crisis and forest cover change in Teknaf, Bangladesh, Rem. Sens. 10 (5) (2018) 689.
[67] A. Braun, F. Fakhri, V. Hochschild, Refugee camp monitoring and environmental change assessment of Kutupalong, Bangladesh, based on radar imagery of Sentinel-1 and ALOS-2, Rem. Sens. 11 (17) (2019) 2047.
[68] E. Dumitrescu, C. Hurlin, Testing for Granger non-causality in heterogeneous panels, Econ. Modell. 29 (4) (2012) 1450–1460.
[69] D. Guha-Sapir, M. Salih, Environment and sudden population displacement: policy issues for humanitarian action and development programmes, The Environmental Impact of Sudden Population Displacement: Priority Policy Issues and Humanitarian Aid (1995) 7–17.
[70] G. Kibreab, Environmental causes and impact of refugee movements: a critique of the current debate, Disasters (1997) 20–38.
[71] UNHCR, The State of the World's Refugees: Tlie Challenge of Protection, Penguin, London, 1993.
[72] J. Kakonge, A Review of Refugee Environmental-Oriented Projects in Africa: a Case for Environmental Impact Assessment, Impact Assessment and Project Appraisal, 2000, pp. 23–32.
[73] D. Filmer, L. Pritchett, Environmental degradation and the demand for children: searching for the vicious circle in Pakistan, Environ. Dev. Econ. 7 (1) (2002) 123–146.
[74] P. Fearnside, W. Laurance, Tropical deforestation and greenhouse-gas emissions, Ecol. Appl. 14 (4) (2004) 982–986.
[75] A. Pfaff, What drives deforestation in the Brazilian amazon? J. Environ. Econ. Manag. 37 (1999) 26–43.
[76] S. Dick, Review of CORD Community Services for Congolese Refugees in Tanzania, United Nations High Commissioner for Refugees, Geneva, 2002.
[77] K. Birendra, S. Nagata, Refugee impact on collective management of forest resources: a case study of Bhutanese refugees in Nepal's Eastern Terai region, J. For. Res. 11 (5) (2006) 305–311.
[78] E. Lyytinen, Household Energy in Refugee and IDP Camps: Challenges and Solutions for UNHCR, 2009.
[79] M. Bizzarri, C. Bellamy, R. Bizzarri, M. Katajisto, R. Patrick, Safe Access to Firewood and Alternative Energy in Kenya: an Appraisal Report, Women's Commission for Refugee Women and Children, New York, 2010.
[80] C. Rogers, B. Sovacool, S. Clarke, Sweet nectar of the Gaia: lessons from Ethiopia's project Gaia, » Energy for Sustainable Development 17 (3) (2013) 245–251.
[81] D. Nath, D. Mwchahary, Population increase and deforestation: a study in Kokrajhar district of Assam, India, International Journal of Scientific and Research Publications 2 (10) (2012) 1–12.
[82] C. Sulaiman, A. Abdul-Rahim, L. Chin, H. Mohd-Shahwahid, Wood fuel consumption and mortality rates in Sub-Saharan Africa: evidence from a dynamic panel study, Chemosphere 177 (2017) 224–231.
[83] M. Bildirici, Ö. Ersin, Nexus between Industry 4.0 and environmental sustainability: a Fourier panel bootstrap cointegration and causality analysis, J. Clean. Prod. 386 (2023), 135786.
[84] R. McNown, C. Sam, S. Goh, Bootstrapping the autoregressive distributed lag test for cointegration, Appl. Econ. 50 (13) (2018) 1509–1521.
[85] W. Enders, J. Lee, The flexible Fourier form and Dickey–Fuller type unit root tests, Econ. Lett. 117 (1) (2012) 196–199.
[86] F. Cottrell, Energy & Society: the Relation between Energy, Social Change, and Economic Development, McGraw-Hill Book Company, 1955.
[87] A. Mazur, E. Rosa, Energy and Life-Style: massive energy consumption may not be necessary to maintain current living standards in America, Science 186 (4164) (1974) 607–610.
[88] M.S. Alam, B.K. Bala, A.M. Z Huq, M.A. Matin, A model for the quality of life as a function of electrical energy consumption, Energy 16 (4) (1991) 739–745.
[89] M. Olsen, The energy consumption turnaround and socioeconomic wellbeing in industrial societies in the 1980s, Adv. Hum. Ecol. (1992) 197–234.
[90] C. Suarez, Energy Needs for Sustainable Development: Energy as an Instrument for Socio-Economic Development, United Nations Development Programme, New York, 1995.
[91] E. Rosa, Cross-national trends in fossil fuel consumption, societal well-being and carbon releases, Environmentally significant consumption: Research directions (1997) 100–109.
[92] M.S. Alam, A. Roychowdhury, K.K. Islam, A.M.Z. Huq, A revisited model for the physical quality of life (PQL) as a function of electrical energy consumption, Energy 23 (9) (1998) 791–801.
[93] A. Pasternak, Global Energy Futures and Human Development: A Framework for Analysis (US Department of Energy Report UCRL-ID-140773), Lawrence Livermore National Laboratory, Livermore, 2000.
[94] Ö. Karasapan, Future Devlopment: Sharing the Burden of the Global Refugee Crisis, 2020.
[95] Global Migration Data Analysis Centre, World Migration Report, 2017.

[96] M. Bildirici, F. Özaksoy, The relationship between woody biomass consumption and economic growth: nonlinear ARDL and causality, J. For. Econ. 27 (2017) 60–69.
[97] A. Pfaff, S. Kerr, R. Cavatassi, B. Davis, A. Sanchez, J. Timmins, Effects of Poverty on Deforestation: Distinguishing Behaviour from Location, Economics of Poverty, the Environment and Natural Resource Use, 2008.
[98] K. Ahmed, W. Long, An empirical analysis of CO2 emission in Pakistan using EKC hypothesis, Journal of International Trade Law and Policy (2013).
[99] B. Saboori, H. Gholipour, E. Rasoulinezhad, O. Ranjbar, Renewable energy sources and unemployment rate: evidence from the US states, Energy Pol. 168 (2022), 113155.
[100] T. Phung, E. Rasoulinezhad, H. Luong Thi Thu, How are FDI and green recovery related in Southeast Asian economies? Econ. Change Restruct. (2022) 1–2.