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# Shock persistency to material consumption, renewable and non-renewable energy resources? A (non)linear evidence from the highest carbon emitting countries

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ABSTRACT

With the need to provide more evidence on the possibility of reducing material resources utilization and dependency i.e., improving material resources efficiency, this study considers 10 countries with the largest cumulative emissions over centuries (Brazil, Canada, China, France, Germany, India, Indonesia, Japan, the UK, and the USA) by employing the linear and non-linear unit root tests with the Fourier function and dataset that covers centuries (1850–2021). Specifically, domestic material consumption was implemented for the period 1970-2019, and 1965-2021 for renewable and non-renewable energy resources. Given the linearity and non-linearity evidence, the investigation reveals whether there is persistent or transitory shock in domestic material consumption, renewable energy (REC), and non-renewable energy sources (REC). For (linearity) unit root test evidence, there are transitory shocks in domestic material consumption only in China, France, Indonesia, and Japan, for China, France, India, Japan, England, and the USA in REC, and in all the countries except Brazil, Canada, Germany, and Indonesia for the NREC series. On the ground of (non-linearity) unit root test, the result reveals that shocks to non-renewable energy consumption are temporary only for Canada, Japan, and the USA and the shocks to renewable energy and domestic material consumptions are permanent in all the examined countries. Indeed, the outcome of these findings offers important knowledge to decision makers on how to carefully develop and implement transitory and persistence policy choices.

## 1. Introduction

Given the significant level of anthropogenic emissions especially carbon dioxide ($CO_2$) emission in the ecosystem arising from human activities, climate change has remained a serious challenge to human survival. Although economic development and growth entail using intellectual and natural resources which largely aggregates humans' demand on the ecosystem vis-a-vis ecological footprint, these human activities interact with the environment in a way that demands the natural regeneration of resources consumed for sustainable development. Specifically, natural resources are replenished and absorbed by demand and supply dynamics of the earth resources including material resources. Moreover, the environment responds (dis)favourably according to consumption intensity of material resources such as the energy resources as illustrated in Appendix 1. Following the Kyoto protocol which was activated in 2005 and with now 192 countries supporting the protocol to inhibit global climate change (United Nations Framework on Climate Change, 2022)[18], there has been increased determination by energy actors and policymakers to development and promote clean energy, and efficient energy and material consumption. This advocacy for development of clean energy and material resource efficiency is hinged on the key advantage of energy transition and resource efficiency to promote green growth and improve environmental sustainability simultaneously [1–4].

For instance, as reported by the World Bank, rapid need for material use among the emerging economies and the age-long increase in material consumption among the high-income economies has continued to fuel global increase in the extraction of raw materials i.e., now at ~ over

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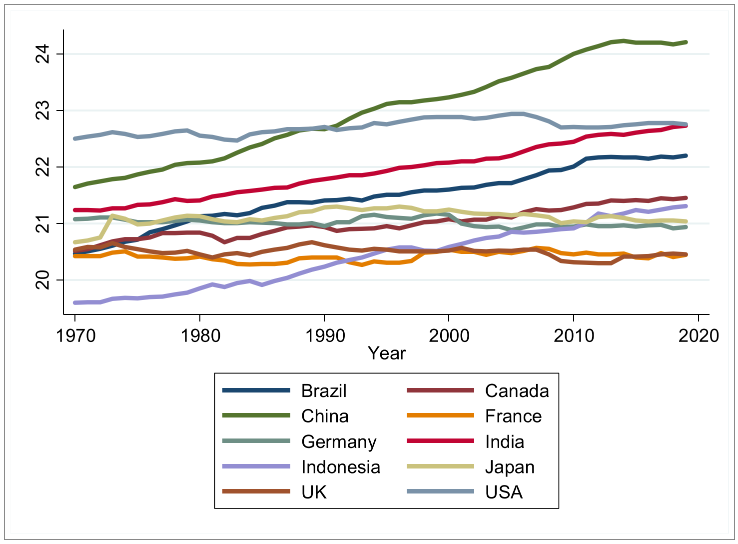


**Fig. 1.** Domestic material consumption series for ten countries (logaritmic values).
**Note**: ('Bra' is Brazil, 'Can' is Canada, 'Chn' is China, 'Fra' is France, 'Ger' is Germany, 'Ind' is India, 'Indo' is Indonesia, 'Jpn' is Japan, 'UK' is the United Kingdom, and 'USA' is the United States of America).

100 billion tons yearly [5]. Although European Union (EU) member countries have experienced improved resource efficiency and economy circularity in the last few decades, this largely contradicts the developing countries' scenario given the desire to increase output and improve economic growth in the developing and emerging economies. A more critical aspect of consumption is the energy resources which is the key input for economic activities. As also reported by the World Bank, the low-income segment of the developing economy have higher consumption expenditure on most essential commodities including energy than the middle and higher segments combined [5]. Intuitively, increased spending on the above-mentioned essentials including clothing and footwear, housing, education, health, water, and energy translates to high material consumption and more distruption of energy transition plan. Importantly, to further understand setback to material and resource efficiency-related policies, it is also essential to understand how these policy pathways are impacted by potential shock effects arising from disruption in economic, socioeconomic, health, and natural activities.

Given this motivation, this study seeks to probe the nature of inherent shocks that potentially drive material consumption and (non) conventional energy sources. Beside the mentioned objective, the study further explore whether this shocks effect on material consumption, renewable and non renewable energy sources is temporary or permanent. To achieve the outlined objective, the case of 10 countries with the largest cumulative emissions over centuries (Brazil, Canada, China, France, Germany, India, Indonesia, Japan, the United Kingdom (UK), and the United States of America (USA)) are considered. Althouhg several studies, including Pothen and Welsch [1], and Kassouri et al. [6] address the aspects of material consumption, there is no sufficient evidence in the literature on the specificity (whether linear or non-linear) of shock effects on material and energy sources. In a novel approach, and by conducting this investigation with the recently developed empirical tool i.e., Fourier-based unit root tests provide both theoretical and empirical contribution to the literature of material and resource efficiency. Specifically, the result of this investigation should offer clearer revelation that could be explored for galvanising policy framework on

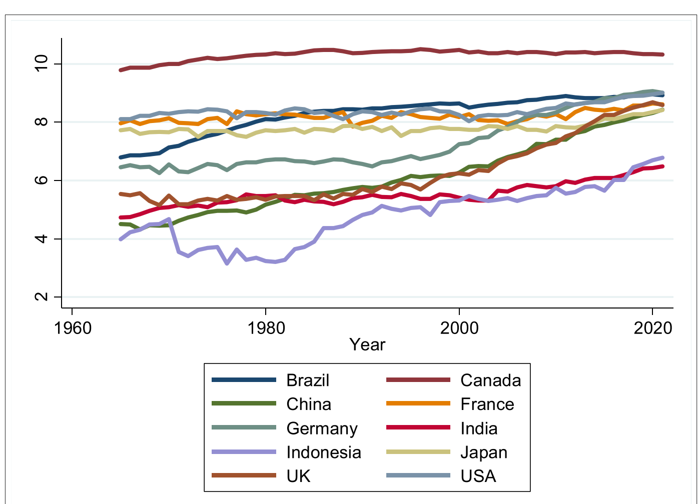


**Fig. 2.** Renewable energy consumption series for ten countries (logaritmic values).
**Note**: ('Bra' is Brazil, 'Can' is Canada, 'Chn' is China, 'Fra' is France, 'Ger' is Germany, 'Ind' is India, 'Indo' is Indonesia, 'Jpn' is Japan, 'UK' is the United Kingdom, and 'USA' is the United States of America).

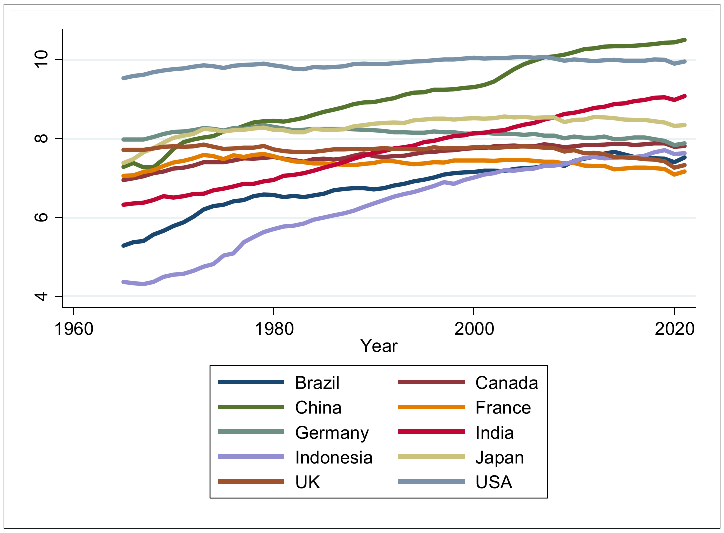


**Fig. 3.** Non-renewable energy consumption series for ten countries (logaritmic values).
**Note:** ('Bra' is Brazil, 'Can' is Canada, 'Chn' is China, 'Fra' is France, 'Ger' is Germany, 'Ind' is India, 'Indo' is Indonesia, 'Jpn' is Japan, 'UK' is the United Kingdom, and 'USA' is the United States of America).

**Table 1**
Traditional unit root test results (ADF and PP unit root tests).

| Panel A. Traditional unit root test results for domestic material consumption series | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ADF | | | | | PP | | | | |
| | C | | C + T | | | C | | C + T | |
| | t-Stat. | Prob. | t-Stat. | Prob. | | t-Stat. | Prob. | t-Stat. | Prob. |
| Brazil | −2.33 | 0.17 | −1.98 | 0.60 | Brazil | −2.16 | 0.22 | −2.07 | 0.55 |
| Canada | 1.72 | 1.00 | −2.41 | 0.37 | Canada | −0.75 | 0.82 | −2.61 | 0.28 |
| China | −0.66 | 0.85 | −3.68[b] | 0.03 | China | −0.73 | 0.83 | −1.94 | 0.62 |
| France | −2.06 | 0.26 | −2.30 | 0.43 | France | −2.10 | 0.24 | −2.35 | 0.40 |
| Germany | −1.93 | 0.31 | −2.81 | 0.20 | Germany | −2.00 | 0.29 | −2.50 | 0.33 |
| India | 0.79 | 0.99 | −3.30[a] | 0.08 | India | 1.13 | 1.00 | −3.30[a] | 0.08 |
| Indonesia | 0.17 | 0.97 | −3.86[b] | 0.02 | Indonesia | 0.24 | 0.97 | −3.25[a] | 0.09 |
| Japan | −3.66[b] | 0.01 | −0.99 | 0.94 | Japan | −3.68[b] | 0.01 | −3.14 | 0.11 |
| UK | −3.08[b] | 0.04 | −3.18 | 0.10 | UK | −2.08 | 0.25 | −2.50 | 0.33 |
| USA | −1.78 | 0.39 | −1.98 | 0.60 | USA | −1.67 | 0.44 | −1.41 | 0.85 |
| Panel B. Traditional unit root test results for renewable energy consumption series | | | | | | | | | |
| ADF | | | | | PP | | | | |
| | C | | C + T | | | C | | C + T | |
| | t-Stat. | Prob. | t-Stat. | Prob. | | t-Stat. | Prob. | t-Stat. | Prob. |
| Brazil | −4.86[c] | 0.00 | −1.56 | 0.80 | Brazil | −4.33[c] | 0.00 | −1.53 | 0.81 |
| Canada | −3.97[c] | 0.00 | −2.23 | 0.47 | Canada | −4.52[c] | 0.00 | −2.69 | 0.24 |
| China | 1.89 | 1.00 | −1.80 | 0.69 | China | 2.14 | 1.00 | −1.80 | 0.69 |
| France | −1.41 | 0.57 | −2.33 | 0.41 | France | −2.61 | 0.10 | −3.48[a] | 0.05 |
| Germany | −1.52 | 0.51 | −2.23 | 0.46 | Germany | 1.39 | 1.00 | −1.50 | 0.82 |
| India | −0.25 | 0.93 | −1.60 | 0.78 | India | −0.25 | 0.93 | −1.64 | 0.76 |
| Indonesia | 0.37 | 0.98 | −5.18[c] | 0.00 | Indonesia | −0.04 | 0.95 | −2.12 | 0.52 |
| Japan | 0.66 | 0.99 | −1.08 | 0.92 | Japan | 0.06 | 0.96 | −1.98 | 0.60 |
| UK | 2.82 | 1.00 | −1.44 | 0.84 | UK | 2.55 | 1.00 | −1.55 | 0.80 |
| USA | −0.57 | 0.87 | −1.41 | 0.85 | USA | −0.31 | 0.92 | −1.34 | 0.87 |
| Panel C. Traditional unit root test results for non-renewable energy consumption series | | | | | | | | | |
| ADF | | | | | PP | | | | |
| | C | | C + T | | | C | | C + T | |
| | t-Stat. | Prob. | t-Stat. | Prob. | | t-Stat. | Prob. | t-Stat. | Prob. |
| Brazil | −4.49[c] | 0.00 | −3.70[b] | 0.03 | Brazil | −3.92[c] | 0.00 | −2.40 | 0.38 |
| Canada | −3.62[b] | 0.01 | −2.61 | 0.28 | Canada | −4.01[c] | 0.00 | −2.70 | 0.24 |
| China | −1.13 | 0.70 | −3.04 | 0.13 | China | −1.54 | 0.50 | −1.90 | 0.64 |
| France | −2.16 | 0.22 | −2.82 | 0.20 | France | −2.42 | 0.14 | −3.01 | 0.14 |
| Germany | −0.76 | 0.82 | −3.84[b] | 0.02 | Germany | −0.77 | 0.82 | −3.21[a] | 0.09 |
| India | −0.42 | 0.90 | −1.80 | 0.69 | India | −0.43 | 0.90 | −1.92 | 0.63 |
| Indonesia | −2.74[a] | 0.07 | 0.51 | 1.00 | Indonesia | −2.43 | 0.14 | 0.40 | 1.00 |
| Japan | −6.62[c] | 0.00 | −4.02[b] | 0.01 | Japan | −6.08[c] | 0.00 | −3.82[b] | 0.02 |
| UK | 1.51 | 1.00 | 0.25 | 1.00 | UK | 0.93 | 1.00 | −0.43 | 0.98 |
| USA | −3.51[a] | 0.01 | −1.39 | 0.85 | USA | −3.52[b] | 0.01 | −2.52 | 0.32 |

Notes: ([a])Significant at the 10 %; ([b])Significant at the 5 %; ([c]) Significant at the 1 %. In addition, C denotes the model with constant, while C + T indicates the model with constant and trend.

material and resource efficiency, and energy transition.

In the other part of the study, the description of the dataset alonside the empirical methods are outlined in section 2. The results of the investigation are discussed in section 3 and the summary of the investion with policy relevance are presented in section 4.

## 2. Data and empirical approach

In this study, we selected the top 10 countries with the largest cumulative emissions over the period 1850–2021 (https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change/). Therefore, the countries used in the study are as follows: Brazil, Canada, China, France, Germany, India, Indonesia, Japan, UK, USA. Although, under the aforementioned conditions, Russia is among the top 10 countries with the highest carbon emissions, France is included instead of Russia due to the lack of data since Russia Federation began after the collapse of the Soviet Union. In this context, we investigated whether the shocks to domestic material consumption (DMC), per capita renewable energy consumption (REC) and non-renewable energy consumption (NREC) are temporary or permanent for the relevant countries with Fourier-based novel unit root tests. In this direction, domestic material consumption data was analyzed for the period 1970–2019 and related data were compiled from the Global Material Flows Database (https://www.resourcepanel.org/global-material-flows-database) (see Appendix 2). Renewable (renewables per capita) and non-renewable energy consumption (global primary energy consumption by fossil fuel source) data were collected from Our Word in Data (https://ourworldindata.org/fossil-fuels, https://ourworldindata.org/energy-mix) for the years 1965–2021 (see Appendix 3 and 4 respectively). Additionally, domestic material consumption is measured in tonnes by weight, while renewable and non-renewable energy consumption is measured in terawatt-hours (TWh). Figs. 1–3 indicates the data used in the study. Fig. 1 reveals that China is the country with the highest domestic material consumption, while the UK and France have the lowest domestic material consumption. Fig. 2 also reveals that Canada has the highest consumption of renewable energy. Indonesia and India are the countries with the lowest consumption of renewable energy. Fig. 3 demonstrates that the USA and China have the highest shares of non-renewable energy consumption. On the other hand, France and the United Kingdom have the lowest non-renewable energy consumption compared to other countries.

However, in the analysis process, we used all series by taking the natural logarithm. In the analysis process, we primarily benefited from unit root tests such as traditional ADF [7] and PP unit root (Philips & Perron, 1988) tests for the relevant variables for the countries covered. Next, the focus is on the Fourier ADF unit root test [8], which softly examines structural breaks in trigonometric terms. In the last stage, we applied the Fourier-Sollis unit root test developed by Ranjbar [9], in which structural breaks are modeled with Fourier functions and nonlinearity is modeled as in Sollis's [10] test. The results of these tests are crucial to improving the effectiveness of policy-makers. In this context, the fact that the shock is permanent indicates that the deviations in the series cannot return to the average without intervention. Applying an effective policy to such a series may have the effect of making the shock temporary. There is no need for intervention when the effects of shocks on the series are temporary. Deviations in the series may spontaneously return to the mean over time. If a series is stationary, the effects of shocks are temporary and it is possible to make predictions about the stationary series in question. On the other hand, for non-stationary series, where the effects of shocks are permanent, it is impossible to make predictions about the future (Narayan and Smith, 2007[16]; Aydın and Pata, 2020).

### 2.1. Econometric methodology

As is known, it can be said that traditional unit root tests such as augmented Dickey-Fuller (ADF) and Phillips-Perron (PP)[17] have relatively weak sides. This is why we focus on unit root tests, which have more powerful features. Accordingly, we discussed the methodological basis of Fourier ADF (2010) unit root test, Sollis [10] nonlinear unit root test, and Fourier-Sollis (2018) unit root tests. In the Fourier ADF test developed by Christopoulos and Leon Ledesman (2010), the structural breaks in the series are modeled in trigonometric terms. This method allows flexible and gradual modeling of break dates instead of sharp break dates caused by dummy variables.

#### 2.1.1. Traditional unit root approach

Meanwhile, we first investigated whether the shocks to domestic material consumption and renewable and non-renewable energy consumption were permanent or temporary, using ADF and PP unit root tests. We reported the results separately for models with both constant and constant and trend in Table 1. For the DMC series, in the constant model of the ADF test, it was concluded that Japan and UK countries were stationary in their level values (therefore, other countries contain a unit root and shocks are permanent), while in the constant and trend model, China, India, and Indonesia were stationary in their level values (therefore, other countries contain a unit root and shocks are permanent). In the PP unit root test, while Japan is stationary in the constant model, India and Indonesia are stationary in level values in the constant and trend model. It is concluded that the shocks to the domestic material consumption series are temporary for the countries that are found to be stationary in level values under these conditions. For the REC series, for the constant model of the ADF and PP unit root test, the countries of Brazil and Canada are stationary at level values. However, we found that in the constant and trend model of ADF, Indonesia is stationary, while in the constant and trend model of PP, France is stationary. It is concluded that the shocks to the REC series are temporary for the countries that are found to be stationary in level values under these conditions. Finally, for the NREC series, in the constant model of the ADF test, Brazil, Canada, Indonesia, Japan, and the USA countries are stationary in their level values, while in the constant and trend model, Brazil, Germany, and Japan are stationary in their level values. In the PP unit root test, it was found that Brazil, Canada, Japan, the USA countries were stationary at the level values in the constant model, while it was stationary at the level values of Germany and Japan in the constant and trend model. To summarise, according to the results of the traditional unit root test, the countries that are stationary at level values have shown that the shocks are temporary for the related series. On the other hand, it is proved that the shocks are permanent for the related series in the countries that are not stationary at level values.

#### 2.1.2. Fourier ADF approach

The Fourier ADF test statistic is as follows ([8]: 1081):

$$y_t = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \sin\left(\frac{2\pi kt}{T}\right) + v_t \tag{1}$$

Here, k is the frequency of the Fourier function, t is the trend, T is the number of observations, and $\pi$ represents 3.1416. The null hypothesis of the test: $H_0 : v_t = \mu_t,\ \mu_t = \mu_{t-1} + h_t,\ h_t$ is assumed to be a zero-mean stationary process. The test statistic is calculated in three stages; in the first step, the appropriate k* frequency is determined. Thus, the selection of the optimal k among the k values between 1 and 5 in the nonlinear deterministic component in the above model will be determined by the least squares estimator (OLS) to be the value that will minimize the residual sum of squares.

$$\widehat{v}_t = y_t - \left[\widehat{\delta}_0 + \widehat{\delta}_1\, sin\left(\frac{2\pi k^* t}{T}\right) + \widehat{\delta}_2\, sin\left(\frac{2\pi k^* t}{T}\right)\right] \tag{2}$$

In the second stage, the OLS residual in the first stage are applied for the unit root. Three separate models with the following linear and non-linear structures are proposed:

**Table 2**
Christopoulos and Leon Ledesma (2010) Fourier ADF unit root test results.

| Countries | DMC | | | REC | | | NREC | | |
|---|---|---|---|---|---|---|---|---|---|
| | k* | FADF | $F_\tau(\hat{k})$ | k* | FADF | $F_\tau(\hat{k})$ | k* | FADF | $F_\tau(\hat{k})$ |
| Brazil | 2 | −2.93 (0) | 24.70 | 1 | −0.66 (0) | 148.23 | 1 | −2.23 (1) | 23.38 |
| Canada | 1 | −3.39 (0) | 15.75 | 1 | −2.64 (0) | 114.41 | 2 | −2.77 (0) | 20.52 |
| China | 3 | −4.20 (1)[b] | 9.55 | 1 | −4.26 (1)[b] | 85.64 | 2 | −4.12 (1)[b] | 27.93 |
| France | 1 | −3.73 (0)[c] | 28.12 | 1 | 5.59 (0)[a] | 20.03 | 2 | −3.04 (0) | 27.24 |
| Germany | 2 | −2.92 (0) | 12.49 | 1 | −2.45 (1) | 220.81 | 1 | −2.33 (0) | 42.55 |
| India | 1 | −3.47 (0) | 11.25 | 1 | −3.98 (0)[b] | 64.67 | 1 | −2.95 (0) | 23.90 |
| Indonesia | 2 | −3.66 (0)[c] | 11.04 | 2 | −2.78 (1) | 39.02 | 1 | −2.19 (0) | 183.36 |
| Japan | 1 | −5.17 (1)[a] | 44.37 | 1 | −4.24 (0)[b] | 18.68 | 1 | −3.27 (1) | 22.91 |
| UK | 3 | −2.76 (0) | 14.00 | 1 | −3.63 (1)[c] | 292.74 | 1 | −3.30 (0) | 51.40 |
| USA | 1 | −2.68 (0) | 32.99 | 1 | −4.02 (0)[b] | 64.07 | 2 | −2.67 (0) | 23.41 |

Notes. ([a]), ([b]) and ([c]) denote the rejection of the unit root null hypothesis at the 1 %, 5 % and 10 % significance, respectively. Table 1 in the article Christopoulos and Leon Ledesma (2010) was taken as a reference for the critical values. We obtained $F_\tau(\hat{k})$ critical values from Becker et al. (2006). Accordingly, $F_\tau(\hat{k})$ were found to be statistically significant when compared with the critical values. Values in parentheses (1) symbolize the optimal lag length. k* represents the optimal frequency.

$$\Delta v_t = \alpha_1 v_{t-1} + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \tag{3}$$

$$\Delta v_t = \rho v_{t-1}\left(1 - \exp\left(-\theta \Delta v_{t-i}^2\right)\right) + \sum_{j=1}^{p} \alpha_j \Delta v_{t-j} + u_t \tag{4}$$

$$\Delta v_t = \lambda v_{t-1}^3 + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \tag{5}$$

Here $\theta > 0$ and $u_t$ denotes the error term. If the null hypothesis expressing the existence of a unit root is rejected in the second stage, that is, if the series is stationary, and then the third stage is passed. In the third stage, the significance of Fourier terms using the F-test $F_\tau(\hat{k})$ is investigated, the null hypothesis ($H_0 : \delta_{11} = \delta_2 = 0$) is tested against the alternative hypothesis ($H_1 : \delta_{11} = \delta_2 \neq 0$). If the null hypothesis is rejected, it is concluded that the series is stationary around the breaking deterministic function.

### 2.1.3. Nonlinear unit root approach

Another unit root test used in the study is the nonlinear unit root test developed by Sollis [10]. Sollis (2009 test proposes an extended version of the exponential smooth transition autoregressive (ESTAR) model. This extended model develops a unit root test that allows for symmetric or asymmetric stationary ESTAR nonlinearity. If the null hypothesis of the existence of a unit root is rejected, a standard F-test is utilized for symmetric and asymmetric ESTAR used to distinguish nonlinearity. The Asymmetric ESTAR (AESTAR) model, which is created using both an exponential function and a logistic function, is produced as follows ([10]: 119).

$$\Delta y_t = G_t(\gamma_1, y_{t-1})\{S_t(\gamma_2, y_{t-1})\rho_1 + (1 - S_t(\gamma_2, y_{t-1}))\rho_2\}y_{t-1} + \varepsilon_t \tag{6}$$

$$G_t(\gamma_1, y_{t-1}) = 1 - \exp\left(-\gamma_1 \left(y_{t-1}^2\right)\right. \quad \gamma_1 \geq 0 \tag{7}$$

$$S_t(\gamma_2, y_{t-1}) = [1 + \exp\left(-\gamma_2 y_{t-1}\right]^{-1} \quad \gamma_2 \geq 0 \tag{8}$$

Where $y_{t-1}$ is assumed to be a transition variable. In addition, $\varepsilon_t \sim$ iid $(0, \sigma^2)$. The condition for global stationarity to be valid in the established model is $\rho_1<0$ $\rho_2<0$ $y_1>0$. If $\rho_1 = \rho_2 = \rho$, Eq. (6) is equal to Kapetanios (2003) symmetrical ESTAR specification (namely, $\Delta y_t = G_t(\gamma, y_{t-d})\rho y_{t-1} + \varepsilon_t)$. As the original symmetrical ESTAR model, the AESTAR model Eq. (6) can be extended to permit for higher order dynamics:

$$\Delta y_t = G_t(\gamma_1, y_{t-1})\{S_t(\gamma_2, y_{t-1})\rho_1 + (1 - S_t(\gamma_2, y_{t-1}))\rho_2\}y_{t-1} + \sum_{i=1}^{k} K_i \Delta y_{t-i} + \varepsilon_t \tag{9}$$

Considering the AESTAR model (Eq. (6), it appears that there are unidentified parameters ($\gamma_1$ and $y_2$) and $\gamma_1$. Sollis [10] creates the following auxiliary regression by applying the first-order Taylor expansion, as in the Kapetanios (2003) unit root test, to overcome this unidentified parameters cases. Therefore, assuming k = 0 in Eq. (6), instead of $G_t(\gamma_1, y_{t-1})$ in Eq. (6) with a first-order Taylor expansion around $y_1 = 0$ uses ([10]: 120).

$$\Delta y_t = \rho_1 \gamma_1 y_{t-1}^3 S_t(\gamma_2, y_{t-1}) + \rho_2 \gamma_1 y_{t-1}^3 S_t(1 - S_t(\gamma_2, y_{t-1})) + \eta_t \tag{10}$$

In Eq. (10) $\eta_t$ equals $\varepsilon_t + R_t$. $R_t$ states the remainder from the Taylor expansion. $\gamma_2$ cannot be defined under the null hypothesis $H_0$: $\gamma_1 = 0$ ($\rho_1$ and $\rho_2$ cannot also be defined). Finding a solution to this problem in Eq. (10), further model is simplified by making Taylor expansion of the logistic function in Eq. (10). In this framework, the expanded form of the model is as follows ([10]: 121).:

$$\Delta y_t = \phi_1 y_{t-1}^3 + \phi_2 y_{t-1}^4 + \sum_{i=1}^{k} K_i \Delta y_{t-i} + \eta_t \tag{11}$$

Thus, it was formed as a new null hypothesis instead of the null hypothesis proposed in Eq. (9) ($H_0$: $\gamma_1 = 0$). Accordingly, the null hypothesis should be $H_0$: $\phi_1 = \phi_2 = 0$. This null hypothesis also indicates that series have a unit root. The alternative hypothesis expressing nonlinear symmetric and asymmetric ESTAR stationarity is $H_1$: $\phi_1 \neq \phi_2 = 0$. In addition, standard critical values are not used to test the null hypothesis. For this, the asymptotic distribution of an F-test of the relevant hypothesis in Eq. (11) is derived ([10]: 121). Ranjbar et al. [9] proposed a new unit root test by adding Fourier terms modeling multiple structural breaks dates to Sollis [10]'s unit root procedure. The model proposed in the framework of Sollis [10] unit root testing is as follows [9]:

$$\Delta \hat{\varepsilon}_t = \psi_1 \hat{\varepsilon}_{t-1}^3 + \psi_2 \hat{\varepsilon}_{t-1}^4 + \sum_{i=1}^{1} l_i \Delta \hat{\varepsilon}_{t-1} + \vartheta_t \tag{12}$$

Where $\sum_{i=1}^{1} l_i \Delta \hat{\varepsilon}_{t-1}$ is used to eliminate the autocorrelation problem with the error term ($\vartheta_t$). The null hypothesis of test is as follows: $H_0$: $\psi_1 = \psi_2$. It has been mentioned above that Sollis [10] does not allow for standard distribution. Undoubtedly, the main feature of the unit root test, also called Fourier-Sollis (2018), developed by Ranjbar [9], is that it models both smooth structural breaks and nonlinearity together.

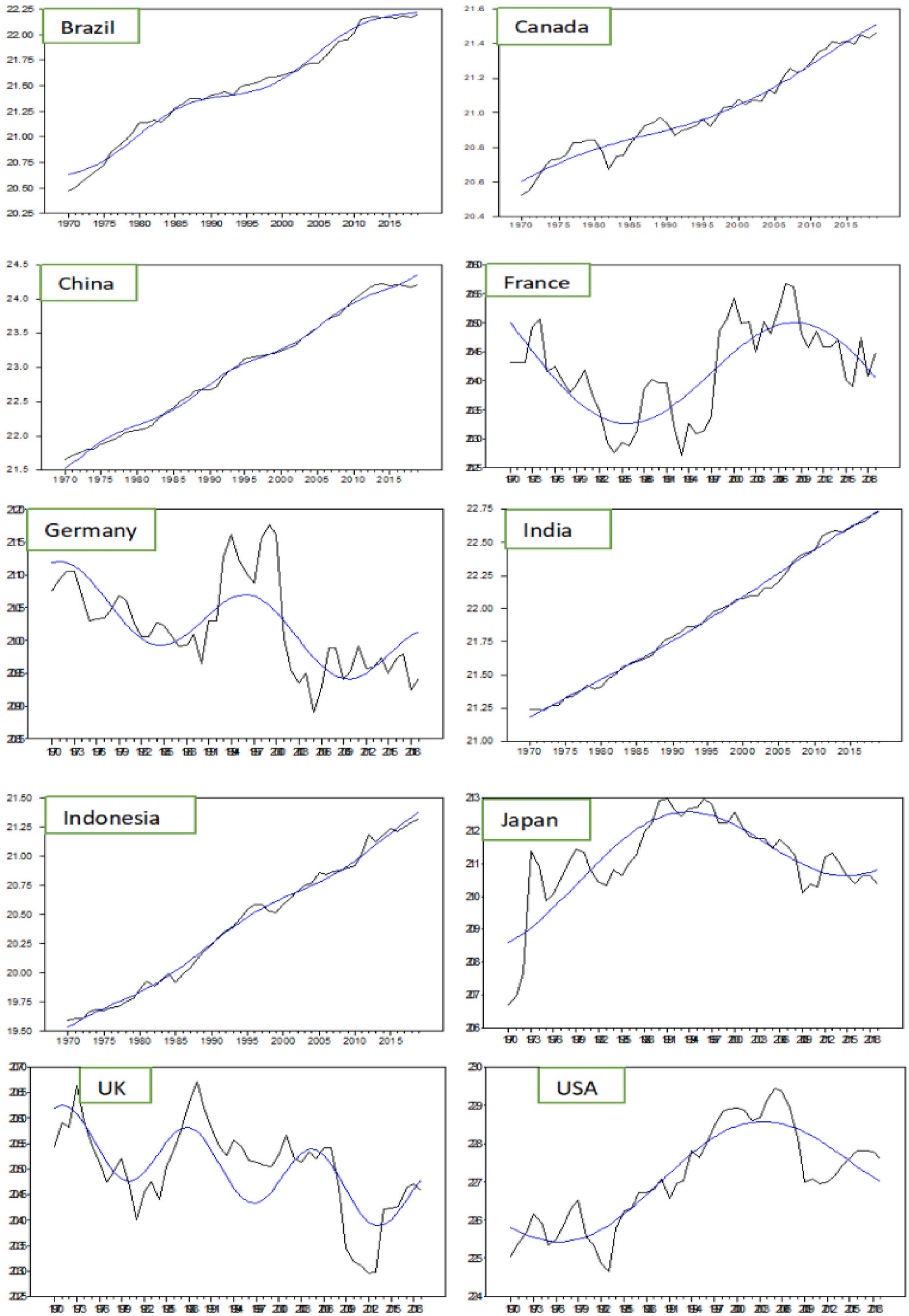


**Fig. 4.** Domestic material consumption series with fourier functions (Blue lines).

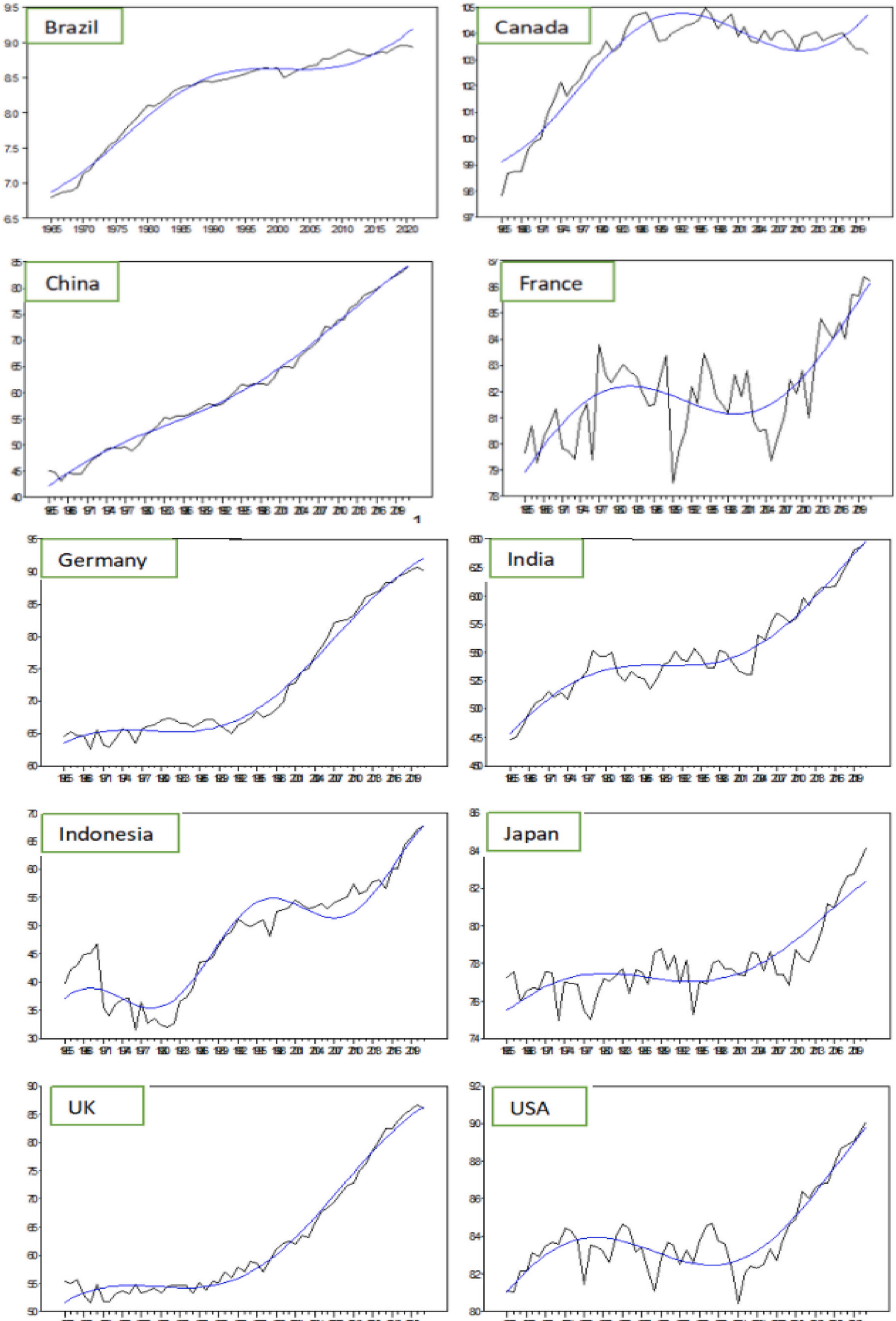


**Fig. 5.** Renewable energy consumption with fourier functions (Blue lines).

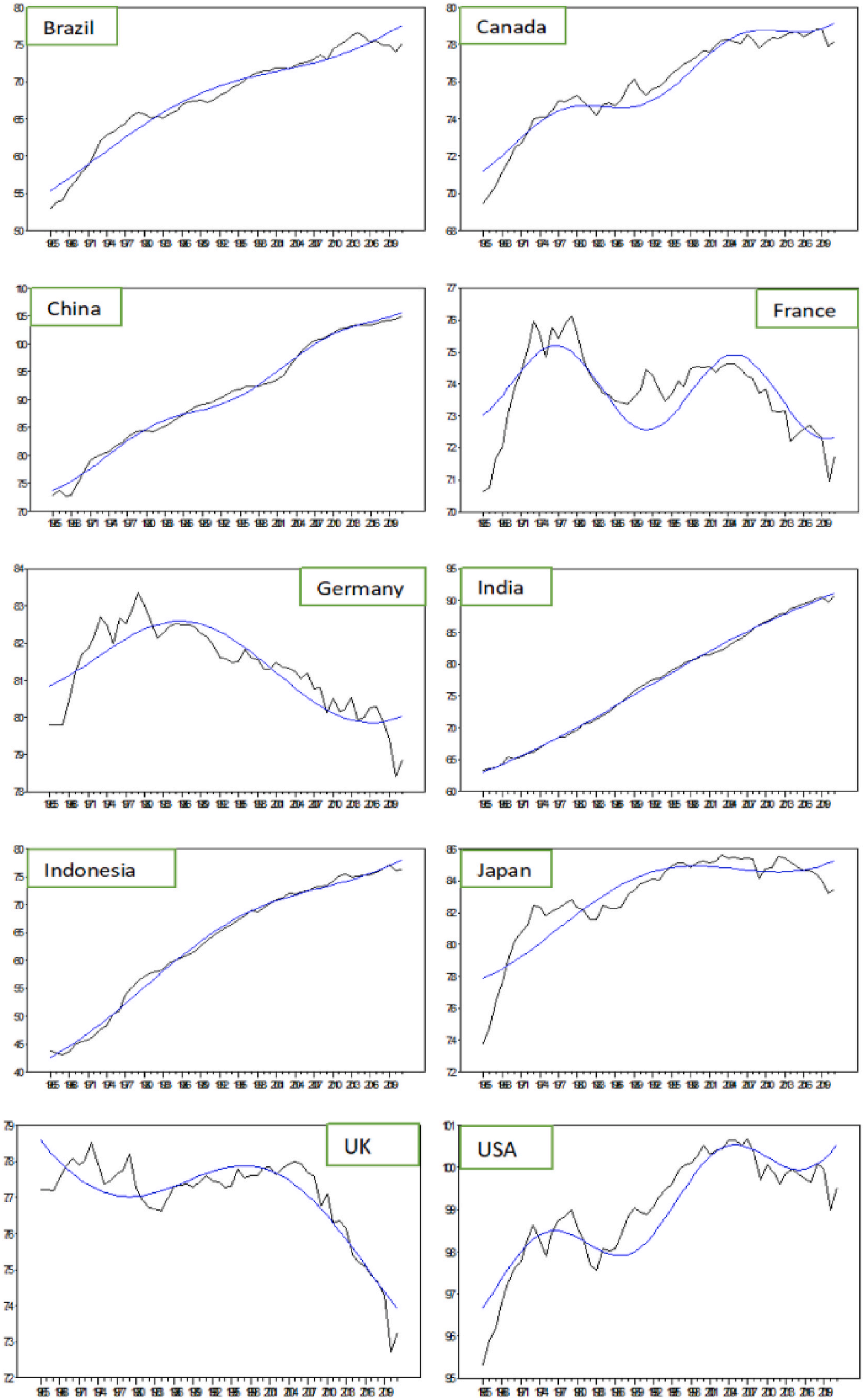


**Fig. 6.** Non-renewable energy consumption series wtih fourier functions (Blue lines).

**Table 3**
BDS linearity test results.

| | | DMC | | NREC | | REC | |
|---|---|---|---|---|---|---|---|
| Countries | Dimension | BDS Stat. | Prob. | BDS Stat. | Prob. | BDS Stat. | Prob. |
| Brazil | 2 | 0.19[a] | 0.00 | 0.20[a] | 0.00 | 0.21[a] | 0.00 |
| | 6 | 0.53[a] | 0.00 | 0.56[a] | 0.00 | 0.58[a] | 0.00 |
| Canada | 2 | 0.17[a] | 0.00 | 0.19[a] | 0.00 | 0.19[a] | 0.00 |
| | 6 | 0.45[a] | 0.00 | 0.51[a] | 0.00 | 0.55[a] | 0.00 |
| China | 2 | 0.20[a] | 0.00 | 0.20[a] | 0.00 | 0.19[a] | 0.00 |
| | 6 | 0.54[a] | 0.00 | 0.55[a] | 0.00 | 0.49[a] | 0.00 |
| France | 2 | 0.11[a] | 0.00 | 0.13[a] | 0.00 | 0.07[a] | 0.00 |
| | 6 | 0.20[a] | 0.00 | 0.32[a] | 0.00 | 0.06[a] | 0.00 |
| Germany | 2 | 0.11[a] | 0.00 | 0.15[a] | 0.00 | 0.18[a] | 0.00 |
| | 6 | 0.24[a] | 0.00 | 0.34[a] | 0.00 | 0.45[a] | 0.00 |
| India | 2 | 0.19[a] | 0.00 | 0.20[a] | 0.00 | 0.16[a] | 0.00 |
| | 6 | 0.53[a] | 0.00 | 0.56[a] | 0.00 | 0.37[a] | 0.00 |
| Indonesia | 2 | 0.19[a] | 0.00 | 0.20[a] | 0.00 | 0.16[a] | 0.00 |
| | 6 | 0.52[a] | 0.00 | 0.57[a] | 0.00 | 0.39[a] | 0.00 |
| Japan | 2 | 0.14[a] | 0.00 | 0.18[a] | 0.00 | 0.11[a] | 0.00 |
| | 6 | 0.35[a] | 0.00 | 0.46[a] | 0.00 | 0.08[a] | 0.01 |
| UK | 2 | 0.11[a] | 0.00 | 0.15[a] | 0.00 | 0.18[a] | 0.00 |
| | 6 | 0.19[a] | 0.00 | 0.27[a] | 0.00 | 0.42[a] | 0.00 |
| USA | 2 | 0.16[a] | 0.00 | 0.17[a] | 0.00 | 0.14[a] | 0.00 |
| | 6 | 0.35[a] | 0.00 | 0.45[a] | 0.00 | 0.24[a] | 0.00 |

Note. ([a]) denotes rejection of the null hypothesis expressing linearity at the 1 %.

## 3. Findings and discussion

Following the traditional unit root test results, the results of the Fourier ADF (2010) test developed by Christopoulos and Leon Ledesma (2010), which gradually models structural breaks in Fourier terms, are presented in Table 2. Accordingly, for the DMC series, it is determined that China, France, Indonesia, and Japan are stationary in their level values. In other words, the results of the Fourier ADF unit root test revealed that shocks to domestic material consumption in the relevant countries are temporary. Shocks to domestic material consumption for the other six countries (Brazil, Canada, Germany, India, the UK, and the US) were found to be permanent. Following that, for the REC series, it is also determined that the level values of China, France, India, Japan, England, and America are stationary. In other words, the shocks to renewable energy consumption are temporary in the mentioned countries. On the other hand, in Brazil, Canada, Germany, and Indonesia, shocks are permanent for the relevant variable. Finally, for the NREC series, only China is found to be stationary at level values. In other words, the result establishes that the shocks to non-renewable energy consumption are temporary in this country. Then, it shows that the other nine countries have a unit root. Accordingly, in these countries, the shocks are permanent. The figures of the variables with Fourier functions for each country are presented in Figs. 4–6. Overall, from the previous studies, there are varying outocmes. For instance, Erdogan et al. [11] establishes permanent shocks on disaggregated energy consumption for Turkey while the Aydin and Pata [12] found permanent shocks for renewable energy sources except in wind and hydropower in the USA. Meanwhile, for the 15 leading countries in renewable energy development (Australia, Brazil, Canada, China, France, Germany, India, Italy, Japan, South Korea, Spain, Sweden, Turkey, the USA, and the UK), Kiran Baygin and Çil (2023)[15] found persistence in shock for non-renewable energy in all the countries except the USA and Sweden. But, for renewable energy, persistence is not found only in Canada, Sweden, and the UK. Although there is mimited information in the literature about the persistence of shock in material consumption and the non-linearity evidence, Pata and Yilanci [13] found more persistence positive and negative shock effect among 10 developed (G-10) countries than the ground of 10 developing (N-10) countries.

### 3.1. Non-linearity evidence

Following Fourier-based unit root tests have made an important contribution to the econometrics literature by gradually modeling structural breaks. In addition, the use of Fourier functions together in nonlinear formations has come to the fore in recent years. In this framework, firstly, whether the variables examined were linear or not was analyzed by using the Brock et al. [14] (known as BDS test) test approach and reported in Table 3. BDS test results showed that the null hypothesis expressing linearity for all countries' variables was rejected. In other words, it has been proven that the relevant series are nonlinear.

Traditional unit root tests have serious shortcomings as they do not consider structural break dates and nonlinearity. Therefore, to obtain more reliable results, Sollis's [10] nonlinear unit root test analysis was performed first, and then we applied the Fourier-Sollis (2018) unit root test, which models structural breaks and nonlinear formations. Table 4 presents the results of the nonlinear unit root test developed by Sollis [10]. For the DMC series, in the non-zero mean model of Sollis's [10] unit root test, only Japan was found to be stationary at level values, while in the deterministic trend model, all countries were found to have a unit root. That is, according to the nonlinear unit root test, the shocks to domestic material consumption are permanent for all countries. Thereafter, the results of the Fourier-Sollis (2018) unit root test, which models the structural break with Fourier functions and considers nonlinearity, are presented. Accordingly, for the DMC series, it clearly shows that at constant, all countries have a unit root, in other words, shocks are permanent. It also reveals that in China, Japan, and the USA, the shocks are stable in the constant and trend model, that is, the shocks are temporary. However, Brazil, Canada, France, Germany, India, Indonesia, and UK countries contain a unit root for the relevant series, that is, shocks are permanent.

Table 5 presents Sollis's [10] and Fourier-Sollis's (2018) unit root test results for the REC series. Sollis's [10] non-linear unit root test

**Table 4**
Sollis [10] and Fourier-Sollis (2018) unit root test for domestic material consumption.

| Countries | Sollis$^{\mu}$ | Sollis$^{\tau}$ | Fourier-Sollis$^{c}$ | k* | MinRSS | Fourier-Sollis$^{c+t}$ | k* | MinRSS |
|---|---|---|---|---|---|---|---|---|
| Brazil | 2.06 (1) | 0.45 (1) | 1.62 (1) | 1 | 6.14 | 2.66 (0) | 2 | 0.18 |
| Canada | 3.24 (0) | 0.61 (1) | 3.91 (0) | 1 | 1.52 | 3.79 (0) | 1 | 0.11 |
| China | 0.18 (1) | 0.10 (1) | 1.13 (1) | 1 | 12.55 | 8.00 (1)b | 3 | 0.19 |
| France | 2.20 (0) | 0.84 (1) | 5.77 (0) | 1 | 0.13 | 5.06 (0) | 1 | 0.11 |
| Germany | 3.81 (0) | 0.56 (1) | 3.39 (0) | 2 | 0.15 | 5.13 (0) | 2 | 0.11 |
| India | 1.50 (1) | 0.13 (1) | 1.12 (1) | 1 | 4.17 | 2.98 (0) | 1 | 0.04 |
| Indonesia | 2.24 (0) | 0.18 (1) | 1.50 (1) | 1 | 5.35 | 6.21 (0) | 2 | 0.10 |
| Japan | 10.5 (1)[a] | 1.82 (1) | 22.75 (1) | 1 | 0.36 | 9.02 (1)c | 1 | 0.27 |
| UK | 2.39(0) | 0.37 (1) | 2.59 (0) | 3 | 0.22 | 2.46 (0) | 3 | 0.16 |
| USA | 2.52 (0) | 0.16 (0) | 3.22 (0) | 1 | 0.18 | 8.74 (1)c | 1 | 0.16 |

Notes. ([a]), ([b]) and ([c]) denote rejection of the unit root null hypothesis at the 1 %, 5 %, and 10 % significance levels, respectively. Critical values are taken from Sollis [10] and Ranjbar et al. [9] articles, respectively. RSS means the residual sum of squares. k value which makes residual sum of squares (RSS) minimum. k* represents the optimal frequency. In addition, values in parentheses (1) symbolize the optimal lag length. The superscripts $^{\mu}$ and $^{\tau}$ represent the non-zero mean, and the deterministic trend, respectively. c denotes the constant model, while c + t displays the constant and trend model.

**Table 5**
Sollis [10] and Fourier-Sollis (2018) unit root test for renewable energy consumption.

| Countries | Sollis$^{\mu}$ | Sollis$^{\tau}$ | Fourier-Sollis$^{c}$ | k* | MinRSS | Fourier-Sollis$^{c+t}$ | k* | MinRSS |
|---|---|---|---|---|---|---|---|---|
| Brazil | 2.61 (1) | 1.45 (1) | 0.74 (1) | 1 | 11.15 | 2.20 (0) | 1 | 0.18 |
| Canada | 6.60 (0)[b] | 3.63 (0) | 4.47 (0) | 1 | 0.77 | 4.75 (0) | 1 | 0.11 |
| China | 2.57 (1) | 2.23 (1) | 2.55 (1) | 1 | 35.02 | 15.19 (1)[a] | 1 | 0.19 |
| France | 3.87 (0) | 2.70 (0) | 10.63 (0) | 3 | 1.32 | 11.71 (0)[b] | 1 | 0.11 |
| Germany | 1.08 (1) | 2.92 (1) | 2.94 (1) | 1 | 16.74 | 4.02 (1) | 1 | 0.11 |
| India | 1.95 (0) | 2.81 (0) | 2.58 (0) | 1 | 6.37 | 9.01 (0)[c] | 1 | 0.04 |
| Indonesia | 1.40 (0) | 4.31 (1) | 1.89 (1) | 2 | 16.53 | 10.78 (1)[a] | 2 | 0.10 |
| Japan | 3.84 (0) | 4.15 (0) | 5.64 (0) | 1 | 1.57 | 7.06 (0) | 1 | 0.27 |
| UK | 1.02 (1) | 2.48 (1) | 2.80 (1) | 1 | 24.34 | 5.24 (1) | 1 | 0.16 |
| USA | 5.21 (0)[b] | 2.42 (0) | 1.96 (0) | 1 | 2.01 | 9.52 (0)[b] | 1 | 0.16 |

Notes. ([a]), ([b]) and ([c]) denote rejection of the unit root null hypothesis at the 1 %, 5 %, and 10 % significance levels, respectively. Critical values are taken from Sollis [10] and Ranjbar et al. [9] articles, respectively. RSS means the residual sum of squares. k value which makes residual sum of squares (RSS) minimum. k* represents the optimal frequency. In addition, values in parentheses (1) symbolize the optimal lag length. The superscripts $^{\mu}$ and $^{\tau}$ represent the non-zero mean, and the deterministic trend, respectively. c denotes the constant model, while c + t displays the constant and trend model.

**Table 6**
Sollis [10] and Fourier-Sollis (2018) unit root test for non-renewable energy consumption.

| Countries | Sollis$^{\mu}$ | Sollis$^{\tau}$ | Fourier-Sollis$^{c}$ | k* | MinRSS | Fourier-Sollis$^{c+t}$ | k* | MinRSS |
|---|---|---|---|---|---|---|---|---|
| Brazil | 3.09 (1) | 3.00 (1) | 1.43 (1) | 1 | 10.71 | 4.45 (0) | 1 | 1.00 |
| Canada | 8.32 (0)[a] | 3.79 (0) | 2.88 (1) | 1 | 1.56 | 3.70 (0) | 2 | 0.22 |
| China | 2.86 (1) | 12.2 (1)[a] | 1.74 (1) | 1 | 22.34 | 13.98 (1)[a] | 2 | 0.46 |
| France | 3.67 (0) | 5.03 (0) | 2.76 (0) | 2 | 0.43 | 2.52 (0) | 2 | 0.41 |
| Germany | 0.73 (0) | 3.70 (0) | 2.57 (0) | 1 | 0.18 | 3.83 (0) | 1 | 0.17 |
| India | 1.62 (1) | 4.61 (0) | 2.72 (1) | 1 | 15.22 | 4.91 (0) | 1 | 0.09 |
| Indonesia | 2.12 (1) | 0.37 (1) | 1.25 (1) | 1 | 24.46 | 1.21 (0) | 1 | 0.39 |
| Japan | 24.9 (0)[a] | 5.76 (1)[c] | 8.38 (1) | 1 | 1.87 | 6.68 (1) | 1 | 0.81 |
| UK | 2.91 (0) | 0.69 (0) | 0.59 (0) | 2 | 0.48 | 8.18 (0)[c] | 1 | 0.16 |
| USA | 6.11 (0)[b] | 4.56 (0) | 9.02 (0) | 1 | 0.34 | 2.74 (0) | 2 | 0.15 |

Notes. ([a]), ([b]) and ([c]) denote rejection of the unit root null hypothesis at the 1 %, 5 %, and 10 % significance levels, respectively. Critical values are taken from Sollis [10] and Ranjbar et al. [9] articles, respectively. RSS means the residual sum of squares. k value which makes residual sum of squares (RSS) minimum. k* represents the optimal frequency In addition, values in parentheses (1) symbolize the optimal lag length. The superscripts $^{\mu}$ and $^{\tau}$ represent the non-zero mean, and the deterministic trend, respectively. c denotes the constant model, while c + t displays the constant and trend model.

results showed that for the REC series, the level values of Canada and the USA countries are stationary at the non-zero mean, in other words, shocks to renewable energy consumption are temporary in these countries. However, in the deterministic trend model, all countries contain a unit root, that is, shocks to renewable energy consumption to are permanent. The result of the Fourier-Sollis (2018) unit root test is also in line with the result of the non-zero mean model of Sollis [10]. However, in the constant and trend model, the countries of China, France, India, Indonesia, and the USA are stationary for the relevant series, whereas Brazil, Canada, Germany, Japan, and UK countries have a unit root, that is, shocks to renewable energy consumption are permanent in these countries.

For the NREC series, Sollis [10] and Fourier-Sollis (2018) unit root test results are shown in Table 6. In the non-zero mean model, Sollis's [10] nonlinear unit root test result revealed that the level values of Canada, Japan, and the USA for the related series are stationary. In these countries, shocks to non-renewable energy consumption are temporary. However, the other nine countries have a unit root. That is, in these countries, the shocks are permanent for the relevant series. In the deterministic trend model, the countries of China and Japan are stationary in level values and shocks to nonrenewable energy consumption are temporary for these countries. It has been determined that the other ten countries have a unit root. Fourier-Sollis (2018) unit root test results indicated that all countries have a unit root in the constant model. That is, shocks are permanent for all countries for the relevant series. In the constant and trend model, the results are parallel, except for China and the UK. To put it more clearly, China and UK countries have a unit root, while the other eight countries are stationary in their level values. Thus, while shocks are permanent in China and the UK, shocks are permanent in eight other countries. An overall summary of all test results is presented in Table 7.

## 4. Conclusion and policy recommendation

### 4.1. Conclusion

To achieve the outlined objective of examining the nature of inherent shock in material consumption, and energy sources, this study considered the case of 10 countries with the largest cumulative emissions over centuries (Brazil, Canada, China, France, Germany, India, Indonesia, Japan, the UK, and the USA). By looking at the dataset that covers 1970-2019 for domestic consumption, and 1965-2021 for renewable and non-renewable energy resources, the Fourier-ADF unit root test developed by Christopoulos and Leon Ledesma (2010), the nonlinearity approach by Sollis's [10] and Fourier-Sollis (2018) unit root test introduced by Ranjbar et al. [9], which takes into account both non-linearity and smooth structural breaks, were deployed for the investigation.

With the (non-linearity) Fourier ADF unit root test approach, Domestic material consumption in China, France, Indonesia, and Japan exibits stationarity at level values. This shows that shocks to domestic material consumption in the relevant countries are temporary. Contrarily, shocks to domestic material consumption for the other six countries (Brazil, Canada, Germany, India, the UK, and the US) are permanent. For the REC series, there is stationarity at level for China, France, India, Japan, England, and the USA. This implies that the shocks to renewable energy consumption are temporary in the mentioned countries. Then, in Brazil, Canada, Germany, and Indonesia, shocks are permanent for the relevant variable. Finally, for the NREC series, only China is found to be stationary at level values, implying a temporary shock. For the other nine countries, the shocks are permanent.

For the (linearity) unit root test result, only the DMC series for Japan exhibit stationary at level, while in the constant and trend model, all countries were found to contain a unit root. That is, the shocks to

**Table 7**
Overview of (non)linear unit root test results.

| Countries | ADF (1979) C | ADF (1979) C+T | PP (1988) C | PP (1988) C+T | Fourier ADF$^c$ (2010) | Sollis$^\mu$ (2009) | Sollis$^\tau$ (2009) | Fourier-Sollis$^c$ (2018) | Fourier-Sollis$^{c+t}$ (2018) |
|---|---|---|---|---|---|---|---|---|---|
| Panel A. The results of (non)linear unit root test for domestic material consumption | | | | | | | | | |
| Brazil | X | X | X | X | X | X | X | X | X |
| Canada | X | X | X | X | X | X | X | X | X |
| China | X | √ | X | X | √ | X | X | X | √ |
| France | X | X | X | X | √ | X | X | X | X |
| Germany | X | X | X | X | X | X | X | X | X |
| India | X | √ | X | √ | X | X | X | X | X |
| Indonesia | X | √ | X | √ | √ | X | X | X | X |
| Japan | √ | X | √ | X | √ | √ | X | X | √ |
| UK | √ | X | X | X | X | X | X | X | X |
| USA | X | X | X | X | X | X | X | X | √ |
| Panel B. The results of (non)linear unit root test for renewable energy consumption | | | | | | | | | |
| | ADF (1979) C | ADF (1979) C+T | PP (1988) C | PP (1988) C+T | Fourier ADF$^c$ (2010) | Sollis$^\mu$ (2009) | Sollis$^\tau$ (2009) | Fourier-Sollis$^c$ (2018) | Fourier-Sollis$^{c+t}$ (2018) |
| Brazil | √ | X | √ | X | X | X | X | X | X |
| Canada | √ | X | √ | X | X | √ | X | X | X |
| China | X | X | X | X | √ | X | X | X | √ |
| France | X | X | X | √ | √ | X | X | X | √ |
| Germany | X | X | X | X | X | X | X | X | X |
| India | X | X | X | X | √ | X | X | X | √ |
| Indonesia | X | √ | X | X | X | X | X | X | √ |
| Japan | X | X | X | X | √ | X | X | X | X |
| UK | X | X | X | X | √ | X | X | X | X |
| USA | X | X | X | X | √ | √ | X | X | √ |
| Panel C. The results of (non)linear unit root test for non-renewable energy consumption | | | | | | | | | |
| | ADF (1979) C | ADF (1979) C+T | PP (1988) C | PP (1988) C+T | Fourier ADF$^c$ (2010) | Sollis$^\mu$ (2009) | Sollis$^\tau$ (2009) | Fourier-Sollis$^c$ (2018) | Fourier-Sollis$^{c+t}$ (2018) |
| Brazil | √ | √ | √ | X | X | X | X | X | X |
| Canada | √ | X | √ | X | X | √ | X | X | X |
| China | X | X | X | X | √ | X | √ | X | √ |
| France | X | X | X | X | X | X | X | X | X |
| Germany | X | √ | X | √ | X | X | X | X | X |
| India | X | X | X | X | X | X | X | X | X |
| Indonesia | √ | X | X | X | X | X | X | X | X |
| Japan | √ | √ | √ | √ | X | √ | √ | X | X |
| UK | X | X | X | X | X | X | X | X | √ |
| USA | √ | X | √ | X | X | √ | X | X | X |

Notes. C denotes the constant model, while C+T displays the constant and trend model. √ shows that the variable is stationary. Under these conditions, shocks are temporary. On the other hand, X indicates that the variable has a unit root. Under these conditions, shocks are permanent.

domestic material consumption are permanent for all countries. For the REC series, at level, Canada and the USA countries exhibit stationary with constant, thus suggesting that shocks to renewable energy consumption are temporary in these countries. However, in the constant and trend model, all countries have a unit root, meaning that shocks to renewable energy consumption are permanent. However, there is slight difference between the approaches of the Fourier-Sollis (2018) and Sollis [10] tests for constant and trend model. Meanwhile, in the constant model for the NREC series, Sollis's [10] nonlinear result revealed that the level values for Canada, Japan, and the USA are stationary. In these countries, it means that shocks to non-renewable energy consumption are temporary while the shocks are permanent for the series in the remaining countries. In the constant and trend model, shocks to nonrenewable energy consumption are temporary in China and Japan given the level stationarity characterisitcs of the series and the reverse is the case for other ten countries. Again, the Fourier-Sollis (2018) results indicate that all countries contain a unit root in the constant model indicating permanent shocks. In the constant and trend model, China and UK countries have unit root. Then, shocks are permanent only in China and the UK.

Of course, these findings are limited since it only captures the shock associated with material consumption and energy resources while the underlying fundamentals of these materials are unaccounted for. As such, fundamentals such as energy prices, exchange rate, and macroeconomic indcators such as inflation and interest rate could be considered in future implementation.

### 4.2. Policy recommendation

In terms of policy relevance, the evidence from the linearity and non-linearity unit root tests could provide policy guidance to decision makers and stakeholders throughout the chain of materials and resources under study. In particular, a more proactive approach to the circular economy is essential in the event of permanent shocks in any of the resources studied. Obviously, none of the countries studied has a promising approach to promoting the circular economy, such as the EU countries. Therefore, it is essential to implement sustainable economic and business models aimed at reducing the use of and dependence on material and natural resources through a policy framework of resource sharing, leasing, reuse, repair, refurbishment and recycling. Increasing investment in research and development (R&D) and entrepreneurial activities is a good approach to promote resource sharing, leasing, reuse, repair, refurbishment and recycling, thus reducing the footprint on the earth's resources. In addition, reducing resource use and dependency is also possible by providing credit and tax subsidies to business and industrial entities for adopting resource circularity processes. Overall, this evidence should further guide decision-makers on the most suitable or appropriate permanent and temporary policy choices. In addition, effective implementation of the approach to reduce resource use and dependency would require improving public awareness of the benefits of resource efficiency by communicating relevant information to households, industry and business actors.

## CRediT authorship contribution statement

**Ali Celik:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Andrew Adewale Alola:** Formal analysis, Writing – original draft, Writing – review & editing.

## Ethical Approval

Not Applicable.

## Consent to Participate

Not Applicable.

## Consent to Publish

Not Applicable.

## Availability of data and materials

As indicated in the text, dataset is freely available in online databases.

## Funding

Not Applicable.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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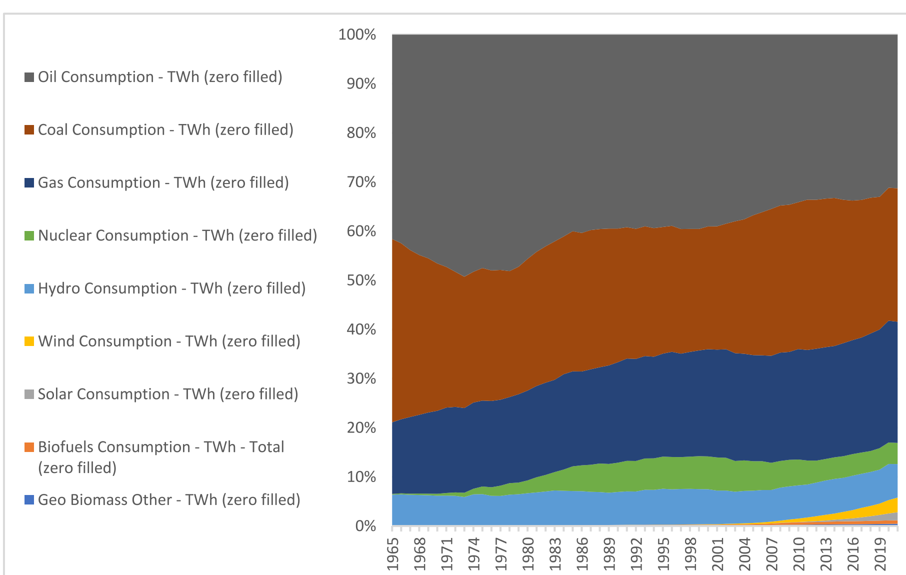
## Appendix 1




World energy consumption by source
Source: BP Statistical Review of World Energy. Primary energy consumption is measured in terawatt-hours (TWh).

*Appendix 2. Domestic material consumption series for ten-countries (logaritmic values)*

| Year | lnbra | lncan | lnchn | lnfra | lnger | lnind | lnindo | lnjpn | lnuk | lnusa |
|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | 20.47 | 20.52 | 21.65 | 20.43 | 21.08 | 21.24 | 19.60 | 20.67 | 20.54 | 22.50 |
| 1971 | 20.51 | 20.55 | 21.71 | 20.43 | 21.09 | 21.24 | 19.61 | 20.70 | 20.59 | 22.54 |
| 1972 | 20.56 | 20.62 | 21.75 | 20.43 | 21.11 | 21.23 | 19.61 | 20.76 | 20.58 | 22.57 |
| 1973 | 20.61 | 20.69 | 21.79 | 20.49 | 21.11 | 21.27 | 19.67 | 21.14 | 20.66 | 22.62 |
| 1974 | 20.68 | 20.73 | 21.81 | 20.51 | 21.07 | 21.27 | 19.69 | 21.09 | 20.59 | 22.59 |
| 1975 | 20.72 | 20.73 | 21.87 | 20.42 | 21.03 | 21.33 | 19.68 | 20.99 | 20.55 | 22.53 |
| 1976 | 20.85 | 20.76 | 21.92 | 20.42 | 21.03 | 21.34 | 19.70 | 21.00 | 20.51 | 22.55 |
| 1977 | 20.90 | 20.83 | 21.96 | 20.40 | 21.03 | 21.38 | 19.71 | 21.06 | 20.48 | 22.59 |
| 1978 | 20.97 | 20.83 | 22.04 | 20.38 | 21.05 | 21.43 | 19.75 | 21.11 | 20.49 | 22.63 |
| 1979 | 21.04 | 20.84 | 22.07 | 20.39 | 21.07 | 21.40 | 19.78 | 21.14 | 20.52 | 22.65 |
| 1980 | 21.13 | 20.84 | 22.08 | 20.42 | 21.06 | 21.41 | 19.86 | 21.13 | 20.46 | 22.56 |
| 1981 | 21.14 | 20.79 | 22.10 | 20.37 | 21.03 | 21.48 | 19.93 | 21.08 | 20.40 | 22.53 |
| 1982 | 21.17 | 20.67 | 22.16 | 20.35 | 21.01 | 21.51 | 19.88 | 21.04 | 20.46 | 22.49 |
| 1983 | 21.15 | 20.75 | 22.26 | 20.29 | 21.01 | 21.56 | 19.95 | 21.03 | 20.48 | 22.47 |
| 1984 | 21.19 | 20.75 | 22.35 | 20.28 | 21.03 | 21.58 | 19.99 | 21.08 | 20.44 | 22.58 |
| 1985 | 21.28 | 20.82 | 22.41 | 20.29 | 21.02 | 21.60 | 19.92 | 21.06 | 20.50 | 22.62 |
| 1986 | 21.32 | 20.87 | 22.51 | 20.29 | 21.01 | 21.63 | 19.99 | 21.10 | 20.54 | 22.63 |
| 1987 | 21.38 | 20.93 | 22.57 | 20.31 | 20.99 | 21.64 | 20.04 | 21.13 | 20.57 | 22.67 |
| 1988 | 21.38 | 20.95 | 22.65 | 20.39 | 20.99 | 21.71 | 20.12 | 21.20 | 20.63 | 22.67 |
| 1989 | 21.37 | 20.97 | 22.68 | 20.40 | 21.01 | 21.76 | 20.19 | 21.22 | 20.67 | 22.68 |
| 1990 | 21.41 | 20.94 | 22.67 | 20.40 | 20.96 | 21.79 | 20.24 | 21.29 | 20.62 | 22.71 |
| 1991 | 21.42 | 20.87 | 22.73 | 20.40 | 21.03 | 21.82 | 20.31 | 21.30 | 20.58 | 22.66 |
| 1992 | 21.44 | 20.90 | 22.86 | 20.32 | 21.03 | 21.86 | 20.36 | 21.27 | 20.54 | 22.69 |
| 1993 | 21.41 | 20.91 | 22.96 | 20.27 | 21.13 | 21.86 | 20.40 | 21.24 | 20.53 | 22.70 |
| 1994 | 21.48 | 20.92 | 23.03 | 20.33 | 21.16 | 21.89 | 20.47 | 21.27 | 20.56 | 22.78 |
| 1995 | 21.51 | 20.96 | 23.12 | 20.31 | 21.12 | 21.93 | 20.54 | 21.27 | 20.54 | 22.76 |
| 1996 | 21.51 | 20.92 | 23.15 | 20.31 | 21.10 | 21.99 | 20.58 | 21.30 | 20.51 | 22.80 |
| 1997 | 21.56 | 20.97 | 23.15 | 20.34 | 21.09 | 22.00 | 20.58 | 21.28 | 20.51 | 22.84 |
| 1998 | 21.59 | 21.03 | 23.18 | 20.49 | 21.15 | 22.03 | 20.53 | 21.22 | 20.51 | 22.88 |
| 1999 | 21.59 | 21.04 | 23.20 | 20.50 | 21.18 | 22.07 | 20.52 | 21.22 | 20.51 | 22.89 |
| 2000 | 21.60 | 21.08 | 23.23 | 20.54 | 21.16 | 22.08 | 20.59 | 21.25 | 20.53 | 22.89 |
| 2001 | 21.63 | 21.04 | 23.28 | 20.50 | 21.00 | 22.10 | 20.64 | 21.21 | 20.57 | 22.89 |
| 2002 | 21.64 | 21.07 | 23.33 | 20.50 | 20.96 | 22.10 | 20.70 | 21.18 | 20.52 | 22.86 |
| 2003 | 21.69 | 21.07 | 23.42 | 20.45 | 20.94 | 22.15 | 20.75 | 21.17 | 20.51 | 22.87 |
| 2004 | 21.72 | 21.13 | 23.52 | 20.50 | 20.95 | 22.16 | 20.77 | 21.17 | 20.53 | 22.91 |
| 2005 | 21.72 | 21.11 | 23.58 | 20.48 | 20.89 | 22.20 | 20.86 | 21.15 | 20.52 | 22.94 |
| 2006 | 21.79 | 21.20 | 23.66 | 20.52 | 20.93 | 22.28 | 20.84 | 21.17 | 20.54 | 22.94 |
| 2007 | 21.86 | 21.26 | 23.73 | 20.57 | 20.99 | 22.36 | 20.86 | 21.15 | 20.54 | 22.89 |
| 2008 | 21.94 | 21.23 | 23.77 | 20.56 | 20.99 | 22.40 | 20.88 | 21.12 | 20.46 | 22.81 |
| 2009 | 21.95 | 21.24 | 23.89 | 20.48 | 20.94 | 22.42 | 20.90 | 21.01 | 20.34 | 22.70 |
| 2010 | 22.01 | 21.29 | 24.00 | 20.46 | 20.95 | 22.45 | 20.92 | 21.04 | 20.32 | 22.71 |
| 2011 | 22.15 | 21.35 | 24.08 | 20.49 | 20.99 | 22.54 | 21.02 | 21.03 | 20.31 | 22.70 |
| 2012 | 22.17 | 21.36 | 24.14 | 20.46 | 20.96 | 22.57 | 21.18 | 21.12 | 20.30 | 22.70 |
| 2013 | 22.18 | 21.41 | 24.21 | 20.46 | 20.96 | 22.59 | 21.13 | 21.13 | 20.30 | 22.71 |
| 2014 | 22.17 | 21.40 | 24.23 | 20.47 | 20.97 | 22.57 | 21.18 | 21.10 | 20.42 | 22.74 |
| 2015 | 22.17 | 21.42 | 24.20 | 20.40 | 20.95 | 22.61 | 21.24 | 21.06 | 20.42 | 22.76 |
| 2016 | 22.15 | 21.40 | 24.20 | 20.39 | 20.97 | 22.64 | 21.21 | 21.04 | 20.43 | 22.78 |
| 2017 | 22.19 | 21.45 | 24.20 | 20.48 | 20.98 | 22.66 | 21.25 | 21.06 | 20.46 | 22.78 |
| 2018 | 22.17 | 21.43 | 24.17 | 20.41 | 20.92 | 22.71 | 21.29 | 21.06 | 20.47 | 22.78 |
| 2019 | 22.20 | 21.46 | 24.21 | 20.45 | 20.94 | 22.73 | 21.31 | 21.04 | 20.46 | 22.76 |

**Note**: ('Bra' is Brazil, 'Can' is Canada, 'Chn' is China, 'Fra' is France, 'Ger' is Germany, 'Ind' is India, 'Indo' is Indonesia, 'Jpn' is Japan, 'UK' is the United Kingdom, and 'USA' is the United States of America).

*Appendix 3. Renewable energy consumption series for ten-countries (logaritmic values)*

| Year | lnbra | lncan | lnchn | lnfra | lnger | lnind | lnindo | lnjpn | lnuk | lnusa |
|---|---|---|---|---|---|---|---|---|---|---|
| 1965 | 6.79 | 9.78 | 4.50 | 7.96 | 6.45 | 4.73 | 3.98 | 7.72 | 5.53 | 8.11 |
| 1966 | 6.86 | 9.87 | 4.49 | 8.07 | 6.52 | 4.75 | 4.22 | 7.76 | 5.50 | 8.11 |
| 1967 | 6.87 | 9.87 | 4.32 | 7.93 | 6.46 | 4.84 | 4.31 | 7.60 | 5.57 | 8.22 |
| 1968 | 6.89 | 9.87 | 4.46 | 8.03 | 6.47 | 4.96 | 4.49 | 7.66 | 5.30 | 8.22 |
| 1969 | 6.94 | 9.96 | 4.45 | 8.07 | 6.25 | 5.05 | 4.51 | 7.67 | 5.16 | 8.32 |
| 1970 | 7.13 | 9.99 | 4.46 | 8.13 | 6.55 | 5.08 | 4.68 | 7.66 | 5.48 | 8.29 |
| 1971 | 7.19 | 10.00 | 4.62 | 7.98 | 6.31 | 5.15 | 3.54 | 7.76 | 5.18 | 8.35 |
| 1972 | 7.33 | 10.09 | 4.73 | 7.97 | 6.29 | 5.10 | 3.40 | 7.75 | 5.18 | 8.37 |
| 1973 | 7.43 | 10.15 | 4.82 | 7.94 | 6.42 | 5.14 | 3.61 | 7.50 | 5.31 | 8.36 |
| 1974 | 7.53 | 10.21 | 4.92 | 8.10 | 6.56 | 5.08 | 3.68 | 7.70 | 5.37 | 8.44 |
| 1975 | 7.60 | 10.16 | 4.95 | 8.15 | 6.53 | 5.24 | 3.71 | 7.70 | 5.31 | 8.43 |
| 1976 | 7.71 | 10.20 | 4.95 | 7.94 | 6.35 | 5.26 | 3.15 | 7.69 | 5.47 | 8.38 |
| 1977 | 7.82 | 10.23 | 4.97 | 8.38 | 6.57 | 5.33 | 3.63 | 7.55 | 5.34 | 8.14 |
| 1978 | 7.91 | 10.28 | 4.90 | 8.27 | 6.62 | 5.52 | 3.27 | 7.50 | 5.37 | 8.35 |
| 1979 | 8.02 | 10.31 | 5.00 | 8.23 | 6.63 | 5.46 | 3.35 | 7.64 | 5.42 | 8.34 |
| 1980 | 8.10 | 10.32 | 5.17 | 8.27 | 6.69 | 5.46 | 3.23 | 7.72 | 5.34 | 8.32 |

(*continued on next page*)

(*continued*)

| Year | lnbra | lncan | lnchn | lnfra | lnger | lnind | lnindo | lnjpn | lnuk | lnusa |
|---|---|---|---|---|---|---|---|---|---|---|
| 1981 | 8.09 | 10.37 | 5.27 | 8.30 | 6.72 | 5.50 | 3.20 | 7.70 | 5.45 | 8.26 |
| 1982 | 8.16 | 10.33 | 5.38 | 8.28 | 6.72 | 5.31 | 3.27 | 7.73 | 5.47 | 8.40 |
| 1983 | 8.22 | 10.35 | 5.51 | 8.26 | 6.66 | 5.25 | 3.65 | 7.77 | 5.47 | 8.47 |
| 1984 | 8.31 | 10.41 | 5.50 | 8.20 | 6.65 | 5.34 | 3.72 | 7.64 | 5.47 | 8.44 |
| 1985 | 8.36 | 10.46 | 5.55 | 8.15 | 6.59 | 5.28 | 3.90 | 7.76 | 5.33 | 8.32 |
| 1986 | 8.39 | 10.47 | 5.56 | 8.15 | 6.65 | 5.27 | 4.36 | 7.75 | 5.52 | 8.34 |
| 1987 | 8.39 | 10.48 | 5.60 | 8.26 | 6.72 | 5.18 | 4.36 | 7.69 | 5.38 | 8.22 |
| 1988 | 8.44 | 10.44 | 5.67 | 8.34 | 6.71 | 5.27 | 4.44 | 7.86 | 5.54 | 8.11 |
| 1989 | 8.45 | 10.37 | 5.73 | 7.85 | 6.63 | 5.39 | 4.64 | 7.88 | 5.51 | 8.28 |
| 1990 | 8.43 | 10.38 | 5.78 | 7.98 | 6.56 | 5.42 | 4.81 | 7.77 | 5.70 | 8.37 |
| 1991 | 8.47 | 10.40 | 5.75 | 8.05 | 6.48 | 5.51 | 4.90 | 7.84 | 5.61 | 8.35 |
| 1992 | 8.47 | 10.42 | 5.79 | 8.22 | 6.63 | 5.43 | 5.12 | 7.70 | 5.79 | 8.25 |
| 1993 | 8.51 | 10.43 | 5.93 | 8.15 | 6.67 | 5.42 | 5.03 | 7.82 | 5.70 | 8.33 |
| 1994 | 8.53 | 10.44 | 6.02 | 8.35 | 6.75 | 5.53 | 4.97 | 7.53 | 5.90 | 8.26 |
| 1995 | 8.55 | 10.45 | 6.16 | 8.28 | 6.83 | 5.46 | 5.05 | 7.70 | 5.85 | 8.38 |
| 1996 | 8.59 | 10.50 | 6.12 | 8.18 | 6.74 | 5.36 | 5.09 | 7.69 | 5.69 | 8.45 |
| 1997 | 8.61 | 10.47 | 6.16 | 8.15 | 6.80 | 5.36 | 4.81 | 7.80 | 5.92 | 8.47 |
| 1998 | 8.64 | 10.42 | 6.17 | 8.12 | 6.88 | 5.52 | 5.26 | 7.82 | 6.11 | 8.38 |
| 1999 | 8.63 | 10.45 | 6.15 | 8.26 | 6.99 | 5.49 | 5.29 | 7.77 | 6.21 | 8.36 |
| 2000 | 8.64 | 10.47 | 6.27 | 8.18 | 7.25 | 5.41 | 5.31 | 7.77 | 6.24 | 8.24 |
| 2001 | 8.50 | 10.39 | 6.47 | 8.28 | 7.29 | 5.34 | 5.46 | 7.74 | 6.20 | 8.04 |
| 2002 | 8.55 | 10.42 | 6.50 | 8.08 | 7.46 | 5.31 | 5.37 | 7.74 | 6.35 | 8.21 |
| 2003 | 8.60 | 10.37 | 6.48 | 8.05 | 7.49 | 5.31 | 5.30 | 7.86 | 6.32 | 8.24 |
| 2004 | 8.63 | 10.36 | 6.68 | 8.06 | 7.71 | 5.65 | 5.34 | 7.85 | 6.58 | 8.23 |
| 2005 | 8.67 | 10.41 | 6.80 | 7.94 | 7.84 | 5.62 | 5.39 | 7.76 | 6.76 | 8.25 |
| 2006 | 8.68 | 10.37 | 6.89 | 8.03 | 8.01 | 5.76 | 5.30 | 7.86 | 6.84 | 8.34 |
| 2007 | 8.76 | 10.40 | 6.99 | 8.11 | 8.21 | 5.85 | 5.40 | 7.74 | 6.94 | 8.27 |
| 2008 | 8.77 | 10.41 | 7.26 | 8.25 | 8.24 | 5.81 | 5.46 | 7.74 | 7.10 | 8.37 |
| 2009 | 8.82 | 10.38 | 7.25 | 8.19 | 8.25 | 5.76 | 5.50 | 7.68 | 7.23 | 8.46 |
| 2010 | 8.86 | 10.33 | 7.40 | 8.28 | 8.33 | 5.81 | 5.75 | 7.87 | 7.28 | 8.49 |
| 2011 | 8.89 | 10.39 | 7.40 | 8.10 | 8.48 | 5.98 | 5.55 | 7.83 | 7.51 | 8.64 |
| 2012 | 8.86 | 10.39 | 7.62 | 8.34 | 8.61 | 5.92 | 5.60 | 7.81 | 7.62 | 8.60 |
| 2013 | 8.83 | 10.41 | 7.70 | 8.48 | 8.65 | 6.03 | 5.77 | 7.88 | 7.85 | 8.66 |
| 2014 | 8.82 | 10.37 | 7.85 | 8.43 | 8.70 | 6.08 | 5.81 | 7.98 | 8.03 | 8.68 |
| 2015 | 8.83 | 10.39 | 7.91 | 8.40 | 8.83 | 6.08 | 5.65 | 8.12 | 8.25 | 8.69 |
| 2016 | 8.87 | 10.40 | 7.99 | 8.46 | 8.83 | 6.08 | 6.02 | 8.10 | 8.24 | 8.78 |
| 2017 | 8.86 | 10.40 | 8.07 | 8.40 | 8.94 | 6.18 | 6.02 | 8.19 | 8.39 | 8.87 |
| 2018 | 8.92 | 10.37 | 8.16 | 8.57 | 8.96 | 6.28 | 6.45 | 8.27 | 8.50 | 8.89 |
| 2019 | 8.96 | 10.34 | 8.24 | 8.57 | 9.03 | 6.41 | 6.56 | 8.27 | 8.58 | 8.91 |
| 2020 | 8.95 | 10.34 | 8.32 | 8.64 | 9.07 | 6.43 | 6.70 | 8.35 | 8.68 | 8.95 |
| 2021 | 8.93 | 10.32 | 8.43 | 8.62 | 9.01 | 6.48 | 6.78 | 8.42 | 8.58 | 9.01 |

**Note:** (‘Bra’ is Brazil, ‘Can’ is Canada, ‘Chn’ is China, ‘Fra’ is France, ‘Ger’ is Germany, ‘Ind’ is India, ‘Indo’ is Indonesia, ‘Jpn’ is Japan, ‘UK’ is the United Kingdom, and ‘USA’ is the United States of America).

*Appendix 4. Non-renewable energy consumption series for ten-countries (logaritmic values)*

| Year | lnbra | lncan | lnchn | lnfra | lnger | lnind | lnindo | lnjpn | lnuk | lnusa |
|---|---|---|---|---|---|---|---|---|---|---|
| 1965 | 5.29 | 6.95 | 7.29 | 7.06 | 7.98 | 6.33 | 4.37 | 7.38 | 7.72 | 9.53 |
| 1966 | 5.38 | 6.99 | 7.38 | 7.07 | 7.98 | 6.36 | 4.34 | 7.48 | 7.72 | 9.59 |
| 1967 | 5.41 | 7.05 | 7.28 | 7.16 | 7.98 | 6.38 | 4.32 | 7.65 | 7.72 | 9.62 |
| 1968 | 5.57 | 7.12 | 7.28 | 7.20 | 8.04 | 6.44 | 4.37 | 7.76 | 7.75 | 9.68 |
| 1969 | 5.67 | 7.17 | 7.48 | 7.31 | 8.12 | 6.54 | 4.50 | 7.90 | 7.79 | 9.73 |
| 1970 | 5.79 | 7.24 | 7.74 | 7.39 | 8.17 | 6.51 | 4.55 | 8.02 | 7.81 | 9.76 |
| 1971 | 5.88 | 7.27 | 7.91 | 7.44 | 8.18 | 6.54 | 4.58 | 8.07 | 7.79 | 9.78 |
| 1972 | 6.02 | 7.32 | 7.98 | 7.50 | 8.22 | 6.60 | 4.65 | 8.12 | 7.80 | 9.82 |
| 1973 | 6.21 | 7.40 | 8.03 | 7.59 | 8.27 | 6.61 | 4.76 | 8.25 | 7.85 | 9.86 |
| 1974 | 6.29 | 7.41 | 8.06 | 7.56 | 8.25 | 6.69 | 4.83 | 8.23 | 7.79 | 9.83 |
| 1975 | 6.33 | 7.41 | 8.18 | 7.48 | 8.20 | 6.74 | 5.04 | 8.18 | 7.74 | 9.79 |
| 1976 | 6.41 | 7.45 | 8.23 | 7.58 | 8.27 | 6.79 | 5.10 | 8.21 | 7.75 | 9.85 |
| 1977 | 6.44 | 7.50 | 8.32 | 7.54 | 8.25 | 6.85 | 5.38 | 8.23 | 7.77 | 9.87 |
| 1978 | 6.54 | 7.49 | 8.41 | 7.59 | 8.29 | 6.85 | 5.51 | 8.26 | 7.77 | 9.88 |
| 1979 | 6.59 | 7.51 | 8.44 | 7.61 | 8.34 | 6.92 | 5.64 | 8.28 | 7.82 | 9.90 |
| 1980 | 6.57 | 7.53 | 8.45 | 7.56 | 8.30 | 6.95 | 5.71 | 8.23 | 7.73 | 9.86 |
| 1981 | 6.52 | 7.49 | 8.43 | 7.48 | 8.26 | 7.06 | 5.78 | 8.21 | 7.69 | 9.82 |
| 1982 | 6.55 | 7.46 | 8.47 | 7.43 | 8.21 | 7.08 | 5.80 | 8.16 | 7.67 | 9.77 |
| 1983 | 6.52 | 7.42 | 8.53 | 7.40 | 8.23 | 7.13 | 5.85 | 8.16 | 7.67 | 9.76 |
| 1984 | 6.56 | 7.48 | 8.60 | 7.37 | 8.25 | 7.19 | 5.95 | 8.25 | 7.66 | 9.81 |
| 1985 | 6.61 | 7.49 | 8.68 | 7.37 | 8.25 | 7.26 | 6.00 | 8.23 | 7.70 | 9.80 |
| 1986 | 6.69 | 7.47 | 8.73 | 7.35 | 8.25 | 7.33 | 6.06 | 8.23 | 7.73 | 9.81 |
| 1987 | 6.73 | 7.50 | 8.80 | 7.34 | 8.25 | 7.40 | 6.11 | 8.24 | 7.73 | 9.84 |
| 1988 | 6.75 | 7.57 | 8.87 | 7.33 | 8.24 | 7.49 | 6.17 | 8.31 | 7.74 | 9.89 |
| 1989 | 6.75 | 7.62 | 8.92 | 7.36 | 8.23 | 7.57 | 6.27 | 8.34 | 7.73 | 9.90 |
| 1990 | 6.72 | 7.56 | 8.93 | 7.38 | 8.22 | 7.64 | 6.36 | 8.38 | 7.74 | 9.89 |
| 1991 | 6.75 | 7.53 | 8.98 | 7.44 | 8.19 | 7.69 | 6.44 | 8.40 | 7.76 | 9.89 |

(*continued on next page*)

(*continued*)

| Year | lnbra | lncan | lnchn | lnfra | lnger | lnind | lnindo | lnjpn | lnuk | lnusa |
|---|---|---|---|---|---|---|---|---|---|---|
| 1992 | 6.81 | 7.56 | 9.03 | 7.43 | 8.16 | 7.75 | 6.53 | 8.41 | 7.74 | 9.91 |
| 1993 | 6.86 | 7.57 | 9.11 | 7.38 | 8.16 | 7.78 | 6.60 | 8.40 | 7.74 | 9.93 |
| 1994 | 6.92 | 7.61 | 9.16 | 7.35 | 8.15 | 7.83 | 6.65 | 8.46 | 7.73 | 9.95 |
| 1995 | 6.96 | 7.65 | 9.18 | 7.37 | 8.15 | 7.91 | 6.73 | 8.49 | 7.73 | 9.96 |
| 1996 | 7.02 | 7.67 | 9.24 | 7.41 | 8.18 | 7.95 | 6.80 | 8.51 | 7.78 | 9.99 |
| 1997 | 7.09 | 7.70 | 9.24 | 7.39 | 8.16 | 8.01 | 6.90 | 8.51 | 7.75 | 10.01 |
| 1998 | 7.12 | 7.71 | 9.25 | 7.45 | 8.16 | 8.06 | 6.86 | 8.48 | 7.76 | 10.01 |
| 1999 | 7.15 | 7.74 | 9.28 | 7.45 | 8.13 | 8.09 | 6.95 | 8.51 | 7.76 | 10.03 |
| 2000 | 7.16 | 7.76 | 9.31 | 7.45 | 8.13 | 8.14 | 7.02 | 8.52 | 7.78 | 10.05 |
| 2001 | 7.19 | 7.76 | 9.36 | 7.45 | 8.15 | 8.15 | 7.09 | 8.51 | 7.79 | 10.03 |
| 2002 | 7.19 | 7.80 | 9.45 | 7.44 | 8.13 | 8.19 | 7.12 | 8.52 | 7.76 | 10.04 |
| 2003 | 7.18 | 7.82 | 9.61 | 7.46 | 8.13 | 8.22 | 7.20 | 8.56 | 7.78 | 10.04 |
| 2004 | 7.23 | 7.83 | 9.76 | 7.46 | 8.12 | 8.29 | 7.19 | 8.54 | 7.79 | 10.06 |
| 2005 | 7.25 | 7.81 | 9.89 | 7.46 | 8.10 | 8.35 | 7.22 | 8.55 | 7.80 | 10.07 |
| 2006 | 7.27 | 7.81 | 9.98 | 7.44 | 8.12 | 8.40 | 7.24 | 8.53 | 7.79 | 10.05 |
| 2007 | 7.31 | 7.86 | 10.06 | 7.42 | 8.08 | 8.48 | 7.31 | 8.54 | 7.77 | 10.07 |
| 2008 | 7.37 | 7.83 | 10.08 | 7.42 | 8.08 | 8.54 | 7.32 | 8.54 | 7.76 | 10.03 |
| 2009 | 7.31 | 7.78 | 10.13 | 7.37 | 8.01 | 8.63 | 7.35 | 8.42 | 7.68 | 9.97 |
| 2010 | 7.44 | 7.81 | 10.19 | 7.38 | 8.05 | 8.66 | 7.43 | 8.47 | 7.71 | 10.01 |
| 2011 | 7.49 | 7.84 | 10.27 | 7.32 | 8.02 | 8.71 | 7.51 | 8.48 | 7.63 | 9.99 |
| 2012 | 7.55 | 7.84 | 10.29 | 7.31 | 8.02 | 8.78 | 7.54 | 8.55 | 7.64 | 9.96 |
| 2013 | 7.62 | 7.85 | 10.33 | 7.31 | 8.05 | 8.81 | 7.50 | 8.54 | 7.61 | 9.99 |
| 2014 | 7.66 | 7.87 | 10.34 | 7.22 | 7.99 | 8.87 | 7.51 | 8.52 | 7.54 | 10.00 |
| 2015 | 7.60 | 7.87 | 10.34 | 7.24 | 8.00 | 8.90 | 7.53 | 8.49 | 7.52 | 9.98 |
| 2016 | 7.53 | 7.84 | 10.35 | 7.26 | 8.03 | 8.95 | 7.53 | 8.47 | 7.51 | 9.97 |
| 2017 | 7.54 | 7.86 | 10.37 | 7.27 | 8.03 | 8.98 | 7.57 | 8.47 | 7.48 | 9.97 |
| 2018 | 7.50 | 7.88 | 10.40 | 7.25 | 7.99 | 9.04 | 7.65 | 8.44 | 7.47 | 10.01 |
| 2019 | 7.49 | 7.88 | 10.43 | 7.23 | 7.94 | 9.05 | 7.71 | 8.41 | 7.43 | 10.00 |
| 2020 | 7.41 | 7.79 | 10.44 | 7.09 | 7.84 | 8.98 | 7.61 | 8.32 | 7.27 | 9.90 |
| 2021 | 7.52 | 7.82 | 10.50 | 7.17 | 7.88 | 9.08 | 7.63 | 8.34 | 7.33 | 9.95 |

**Note:** ('Bra' is Brazil, 'Can' is Canada, 'Chn' is China, 'Fra' is France, 'Ger' is Germany, 'Ind' is India, 'Indo' is Indonesia, 'Jpn' is Japan, 'UK' is the United Kingdom, and 'USA' is the United States of America).

## Data availability

Data will be made available on request.

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