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THE IMPACT OF ENERGY CONSUMPTION ON ECONOMIC GROWTH: APPLICATION OF CES FUNCTION FOR ROMANIA

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Abstract. This paper analyses the contribution of the renewable and non-renewable primary energy consumption per capita and the gross fixed capital formation per capita to sustainable economic growth using two models approximated by CES-type functions. Estimates are made by applying the TRANSLOG method. The results obtained following the analysis of data over a period of 33 years (1990–2022), show that only the increase in gross fixed capital formation per capita contributes to the economic growth. The increase of the consumption of renewable primary energy per capita, respectively of non-renewable primary energy leads to decreases of real GDP per capita. The Granger causality test, reflects that only non-renewable primary energy consumption per capita has a unidirectional causality relation with real GDP per capita. Also, the technical efficiency of inputs in relation to GDP, analysed through an SFA model, suggests that, in general, the resources are used efficiently in the case of Romania. The current inability of renewable primary energy consumption to generate increases in real GDP per capita can be an aspect for policymakers to consider in their efforts to adapt successful low-carbon energy transition models to national needs, so that renewable energy becomes a determinant with a positive and substantial influence on economic growth.

Keywords: economic growth, gross capital formation, energy consumption, CES function, TRANSLOG method, technical efficiency.

JEL Classification: O11, C30, C52, Q43.

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Abbreviations

NECP – National Energy and Climate Plan;
CES – Constant Elasticity of Substitution;
SFA – Stochastic Frontier Analysis;
ADF – Argument Dickey-Fuller;
PP – Phillips-Perron;
OECD – Organisation for Economic Cooperation and Development;
TRANSLOG – Logarithmic Transcendental;
F-statistic – Statistica Fisher;
Durbin-Watson stat – Durbin-Watson statistics;
CUSUM – Cumulative Sum;
VIF – Variance Inflation Factor.

1. Introduction

The challenge posed by climate change and the alarming degradation of the environment has led countries around the world to reconsider the ways in which they can ensure sustainable development, improve the standard of living and the well-being of citizens. As for centuries, economic development was based on increasing energy production and consumption, without taking too much into account the effects of pollution cause by the use of fossil fuels, the traditional energy system proved to be necessary to be reformed into a decarbonized system, fit for the 21st century, focusing now on developing renewable energy and increasing energy efficiency.

Romania needs not only to adopt the energy and climate targets set by transposing them into national legislation and in the form of strategies, policies and measures, which take into account the country specification, but also to monitor and report on the progress made, demonstrating its concern for achieving them within the assumed timeframe. This fact requires changes of the national energy mix, by expanding the share of clean energy sources and reducing polluting ones, without this endangering energy security.

Thus, according the 2025–2030 Integrated National Energy and Climate Plan of Romania (European Commission, 2024), the energy from renewable sources in gross final consumption of energy reached 6,096 ktoe out of a total of 25,254 ktoe in 2022 and 6,919 ktoe out of a total of 24,636 ktoe in 2023. Projection shows that the share of energy from renewable sources in gross final consumption of energy was 24.1% in 2022 and is expected to increase to 31% in 2025, reaching the assumed target of at least 38.3% in 2030 due to wind and solar energy generation capacities, along with heat pumps for heating and cooling.

Progress has also been made on greenhouse gas emissions. Romania follows a downward trend with values that have decreased from 230,408 kt CO_2-eq in 1990 to 63,249 kt CO_2-eq in 2022, achieving by 2022 85% of its 2030 target for net GHG emission reduction.

The statistical data on Romania's energy mix (National Institute for Statistics – Romania, n.d.) reflect important changes at the level of primary energy sources, by decreasing the proportion of coal from 23.89% in 1992 to 8.06% in 2022, of natural gases from 41.06% to 27.17%, simultaneously with an increase in the proportion of hydroelectric, nuclear and energy from unconventional sources as geothermal or wave energy.

Because it is considered important not only the achievement of the assumed targets concerning the proportion of renewable energy in gross final energy consumption and its structure by types of energy sources, but also the consequences on sustainable development, this paper intends to examine the contribution made by renewable and non-renewable primary energy consumptions per capita (REC, respectively NREC) on the economic growth of Romania over 33 years (1990–2022). The contribution of gross fixed capital formation per capita (GFCF) to real GDP per capita (RGDP) evolution is also taken into account.

Since the transition to sustainable development models considers the energy component, it is required to investigate the role played by it in as many geographical contexts as possible, or type of consumers (Oprea et al., 2018). Thus, this study achieves not only a completion of the existing literature related to the role played by non-renewable and renewable energy in sustainable development, but also the highlighting of the link between them.

The present research is also necessary in light of the fact that Romania is among the European Union states with significant gaps to close in transitioning to a more sustainable energy production and consumption model, compared to the leading countries in Northern Europe and even those from Western European countries (Popescu et al., 2022), thus proving more vulnerable in the low-carbon energy transition (Niță et al., 2024; Voicu-Dorobanțu et al., 2021). Therefore, knowing the current situation has the role of helping decision-makers in determining the efficient way forward.

The body of the paper is structured as follows: Section 2 discusses the literature review. Section 3 presents the data and econometric models used whilst Section 4 covers the presentation of results, followed in Section 5 which contains the best performing model and the study of the technical efficiency. Section 6 contain the discussions of the empirical findings. The study conclusion is presented in the final, along with the perceived limitations of the study.

2. Literature review

It is justified for research to investigate the type of relation between renewable energy consumption, non-renewable energy consumption and economic growth and the intensity of this link, given that clean energy sources are expected to meet energy needs that support economic growth and to address issues related to preventing environmental degradation. Over the past two decades, the study of the relationship between GDP and energy (both renewable and non-renewable) has expanded significantly (Mirziyoyeva & Salahodjaev, 2023); the researchers' concerns are related to revealing the existence of a unidirectional or bi-directional link, short-run or long-run causality between those variables, as well as revealing the intensity of this relation.

The studies reported mixed results (AlKhars et al., 2020). Thus, while some studies highlighted a bidirectional causality between economic growth, renewable and non-renewable energy consumption (Atta Mills et al., 2020; Azam et al., 2021), other studies only revealed the presence of unidirectional causality running from output to renewable energy consumption (Ben Mbarek et al., 2018; Ocal & Aslan, 2013) or the other way round, running from renewable energy to gross domestic product (Deka et al., 2023; Liu, 2022; Gyimah et al., 2022; Formánek, 2020). Other studies even indicated the absence of causal relationships between output and renewable energy consumption (Ali et al., 2022; Li & Leung, 2021; Ozcan & Ozturk, 2019).

Regarding highlighting a unidirectional causality of renewable and non-renewable energy production and consumption on economic growth, again the findings are inconclusive, although most of them show a positive relationship between the production and consumption of renewable and non-renewable energy and economic growth (Espoir et al., 2023; Bouyghrissi et al., 2021; Okumus et al., 2021). For Ali et al. (2022) the empirical outcomes show that economic growth is substantially influenced by both clean and non-clean energy consumption. This time, a negative effect on the economic growth due to the increase in renewable energy consumption is indicated in the research conducted by Magazzino and Brady (2018), by Venkatraja (2019) or by Dogan (2015).

The neutrality hypothesis is also confirmed by several studies on countries like Africa (Banday & Aneja, 2020; İnal et al., 2022) or seven OECD countries in Europe (Li & Leung, 2021); the outcomes are not likely to lead the authors to recommend encouraging the use of renewable energy as a means to foster economic growth.

In terms of highlighting the relationship between energy and economic growth in the case of Romania, previous studies have either highlighted a lack of causality between renewable energy and gross domestic product (Simionescu et al., 2019; Sahlian et al., 2021; Marinaș et al., 2018), or the existence of a positive linkage between fossil fuel consumption, alternative and nuclear energy, and economic growth, while "renewable energy usage has an adversative relationship with economic growth" (Rehman et. al., 2022).

By using linear regression, Aceleanu et al. (2018) highlighted a strong positive interdependence between energy consumption from renewable sources and GDP per capita in predominantly rural areas, the results obtained leading the authors to conclusion that sun, wind and water represent sources of renewable energy that can be the basis of ensuring a sustainable development of a Romanian rural space. Still a positive influence exerted by the consumption of renewable energy on real GDP per capita is demonstrated by the research carried out by Mohammadi et al. (2023) or by Doran et al. (2023).

3. Methodology of the research

The current research analyses the influence that renewable and non-renewable primary energy consumption per capita and gross fixed capital formation per capita have on the real GDP per capita in Romania, based on two models approximated by a CES-type function.

The analysis is carried out from two perspectives, one in which the CES function incorporates technical progress, and the other where the CES function is without technical progress, the applied procedure being the TRANSLOG representation (Logarithmic Transcendental).

To analyze the evolution and influence of the three variables on the economic growth, various criteria are used to measure the performances of the two models.

3.1. Data and sources

The current research uses Romania's annual time series data, from 1990 to 2022 to determine the effect of renewable and non-renewable primary energy consumption per capita, and gross fixed capital formation per capita on economic growth, measured by real GDP per capita.

Table 1. Variable description and data source

Index	Variables	Measurement	Data source
The dependent variable			
RDGP	Real Gross Domestic Product per capita	thousand lei per capita (constant prices)	World Bank (n.d.)
The independent variables			
GFCF	Gross fixed capital formation per capita	thousand lei per capita (constant prices)	World Bank (n.d.)
REC	Renewable primary energy consumption per capita	thousands kWh per capita	Ritchie et al. (2020)
NREC	Non-renewable primary energy consumption per capita	thousands kWh per capita	Ritchie and Rosado (2020)

Data series have been extracted in the case of RGDP and GFCF from World Bank (n.d.), and in the case of REC and NREC from Our World in Data (Ritchie et al., 2020; Ritchie & Rosado, 2020) as given in Table 1. In order to transform the data series of the variables mentioned above, per capita, they were related to the number of the population in Romania for the analyzed period.

In order to give a general outlook on the level of the four analyzed variables, Figure 1 shows the time variations of these. It can be noticed that all variables have a sinuous evolution.

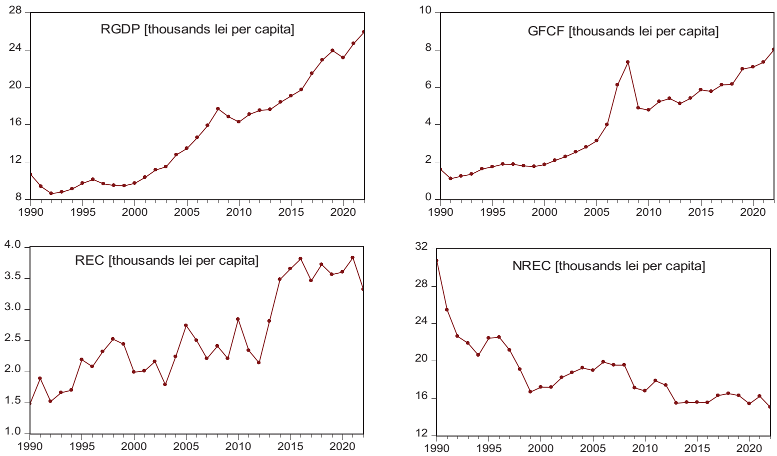


Figure 1. Time series trend of the variables (1990–2022) (source: authors' compilation from World Bank n.d.; Ritchie et al., 2020; Ritchie & Rosado, 2020)

While RGDP, GFCF and REC are on an upward trend, NREC has a downward trend. Even though Romania holds the last place in the European Union in terms of RGDP, it experienced a period of growth during the analyzed period, except the years 1991, 1992, 1997–1999, 2009, 2010 and 2020, reaching a maximum of 25,93 thousand lei per capita in 2022 (according to World Bank, n.d.). Similarly, GFCF recorded a constant upward evolution, reaching a level of 7.35 thousand lei per inhabitant in 2018, only to decrease by approximately 33% in the following year, the increase being resumed with small fluctuations starting from 2011 reaching a level of 8 thousand lei per capita in 2022.

If we consider REC, fluctuations in the size of the values are very frequent (even from one year to the next), but reporting the values from the ends of the analysis interval can lead to the theory that it increased during the analyzed period. Regarding NREC, there is an alternation of periods of decrease with periods of increase, but even in this case, the trend can be seen as decreasing.

3.2. Proposed estimation framework

In this study we analyze the relation between real GDP per capita, dependent variable as proxy for economic growth, and three independent variables, namely gross fixed capital formation per capita, renewable and non-renewable primary energy consumption per capita.

The modelling is done through a CES type function and takes into account the following two situations:

- the CES function is without technical progress;
- the CES function incorporates technical progress (the time variable appears explicitly in the model).

3.2.1. Defining the approximate model by a CES production function

The nonlinear model represented by a CES-type production function (in generalized form), defined by means of *n* independent (exogenous) variables has the following expression (Kmenta, 1967):

$$Y_t = F\left(X_1, X_2, ..., X_k\right) = a\left(\beta_1 X_{1t}{}^{-\xi} + \beta_2 X_{2t}{}^{-\xi} + ... + \beta_n X_{nt}{}^{-\xi}\right)^{-\frac{\mu}{\xi}} \cdot e^{\varepsilon_t}, t = \overline{1, T}, \tag{1}$$

where Y_t is the output variable, $a > 0$ is the efficiency parameter of the production process, $\xi \in \left[-1, \infty\right)$ is a substitution parameter of the factors participating in the production process, X_t are the exogenous variables that have significance as factors of production, μ represents the degree of homogeneity and acts as a scale parameter for the process. Also, ε_t is the residual variable and $\sum_{k=1}^{n} \beta_k = 1$, β_k are the model parameters.

The case in which $\mu = 1$ is a restrictive one studied by (Blackorby & Russel, 1989). If the production process depends on two factors of production, the CES production function first proposed by (Arrow et al., 1961) is obtained. Also, if the substitution parameter $\xi = 0$ the model represented by the Cobb-Douglas production function is obtained (which is a particular case of the model represented by the CES function). The parameters of the model defined in relation (1) have the properties (Stoicuța & Stoicuța, 2015).

The elasticity of substitution σ (the constant), is determined with the help of the substitution parameter ξ:

$$\sigma = \frac{1}{1+\xi}. \tag{2}$$

1. The return to scale μ depends on the value of the parameter ξ. Therefore, we have three situations:
- If $\mu < 1$, the CES production function has decreasing returns to scale;
- If $\mu = 1$, the production function is with constant yield to scale;
- If $\mu > 1$, the production function is with increasing returns to scale.
2. Considering the case where $\mu = 1$, we have the cases:
- If $\xi \to 0$, then $\sigma = 1$; in this case the Cobb-Douglas production function is obtained (a particular case of the CES function);
- If $\xi \to \infty$, then $\sigma \to 0$; in this case leading to the Leontief function (perfect complementarity of production factors).
- The CES production function defined in relation (1) is homogeneous of degree μ if the following equality occurs:

$$F\left(\lambda X_1, \lambda X_2, ..., \lambda X_k\right) = \lambda^{\mu} F\left(X_1, X_2, ..., X_k\right),\ \lambda > 0. \tag{3}$$

If $\mu = 1$ (i.e., the production function is of constant yield), the CES production function is homogeneous of the first degree.

In the study carried out in this article, the non-linear model represented by the CES function without technical progress (called Model 1) is defined in the following relation:

$$RGDP_t = a\left(\beta_1 GFCF_t{}^{-\xi} + \beta_2 REC_t{}^{-\xi} + \beta_3 NREC_t{}^{-\xi}\right)^{-\frac{\mu}{\xi}} \cdot e^{\varepsilon_t},\ \sum_{k=1}^{3} \beta_k = 1,\quad t = \overline{1, T}, \tag{4}$$

where $RGDP_t$ is real Gross Domestic Product per capita and it is the dependent variable, also $GFCF_t$ gross fixed capital formation per capita, REC_t the consumption of renewable primary energy per capita, $NREC_t$ the consumption of non-renewable primary energy per capita, are the three independent variables involved in the model, ε_t is the residual variable that has the normal distribution $N(0, \sigma_\varepsilon^2)$.

If the function incorporates technical progress (the time variable appears explicitly in the model), the nonlinear model represented by the CES function with technical progress (called Model 2) is defined in the following relation:

$$RGDP_t = a\left(\beta_1 GFCF_t^{-\xi} + \beta_2 REC_t^{-\xi} + \beta_3 NREC_t^{-\xi}\right)^{-\frac{\mu}{\xi}} \cdot e^{ct+\varepsilon_t}, \quad \sum_{k=1}^{3}\beta_k = 1, t = \overline{1,T}, \tag{5}$$

where c represents the technical progress.

3.2.2. The TRANSLOG approximation of the three-input CES function

Since the nonlinear CES function cannot be analytically linearized, in this study we will use the TRANSLOG (logarithmic transcendental) approximation. The TRANSLOG function has been widely used for empirical economic research after being introduced by Christensen et al. (1973).

Starting from the work proposed by (Kmenta, 1967), in which the author presents a linearized form of the two-input CES function, by applying Taylor's formula (and keeping only the first two terms from the development), in 2004, Hoff presents a model in which he used the TRANSLOG method for one output and four inputs of the CES function, for 156 observations (monthly data).

In the general case, the TRANSLOG method applied for a CES function of the form (1), has the following representation.

$$\ln Y_t = \ln a + \sum_{i=1}^{n}\alpha_i \ln X_{it} + \sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_{ij}\ln X_{it}\ln X_{jt} + \varepsilon_t, \tag{6}$$

for which the parameters are subject to the following conditions (Hoff, 2002):

$$\text{I. } \alpha_k = \mu\beta_k; \tag{7}$$

$$\text{II. } \sum_{k=1}^{n}\alpha_k = \mu; \tag{8}$$

$$\text{III. } \left.\frac{\alpha_{ij}}{\alpha_i\alpha_j}\sum_{k=1}^{n}\alpha_k\right|_{i\neq j} = \frac{2\alpha_{ii}}{\alpha_i^2 \Big/ \sum_{k=1}^{n}\alpha_k - \alpha_i} = \frac{2\alpha_{jj}}{\alpha_j^2 \Big/ \sum_{k=1}^{n}\alpha_k - \alpha_j} = \xi \text{ or}$$

$$\left.\alpha_{ij}\right|_{i\neq j} = \frac{-2\alpha_{ii}}{1+\sum_{k\neq(i,j)}\frac{\alpha_k}{\alpha_j}} = \frac{-2\alpha_{jj}}{1+\sum_{k\neq(i,j)}\frac{\alpha_k}{\alpha_i}}, \tag{9}$$

where $\alpha_k, k = \overline{1,n}$ are linear coefficients which in the model act as elasticities.

In this article, the TRANSLOG method of approximating the CES function represented in Model 1 (in the case where we have one output and three inputs), has the following representation:

$$\begin{aligned} \ln RGDP_t &= \ln a + \alpha_1 \ln GFCF_t + \alpha_2 \ln REC_t + \alpha_3 \ln NREC_t + \\ &\alpha_{11}\left(\ln GFCF_t\right)^2 + \alpha_{22}\left(\ln REC_t\right)^2 + \alpha_{33}\left(\ln NREC_t\right)^2 + \\ &\alpha_{12}\ln GFCF_t \cdot \ln REC_t + \alpha_{13}\ln GFCF_t \cdot \ln NREC_t + \alpha_{23}\ln REC_t \cdot \ln NREC_t + \varepsilon_t, \end{aligned} \tag{10}$$

where $\alpha_{ij} = \alpha_{ji}, \forall i, j = \overline{1,3}, \quad \sum_{k=1}^{3}\alpha_k = \mu, \quad t = \overline{1,T}$.

Regarding Model 2, the TRANSLOG approximation of the CES function with technical progress has the following representation:

$$\begin{aligned}\ln RGDP_t &= \ln a + \alpha_1 \ln GFCF_t + \alpha_2 \ln REC_t + \alpha_3 \ln NREC_t + \\ &\alpha_{11}\left(\ln GFCF_t\right)^2 + \alpha_{22}\left(\ln REC_t\right)^2 + \alpha_{33}\left(\ln NREC_t\right)^2 + \\ &\alpha_{12} \ln GFCF_t \cdot \ln REC_t + \alpha_{13} \ln GFCF_t \cdot \ln NREC_t + \alpha_{23} \ln REC_t \cdot \ln NREC_t + ct + \varepsilon_t\end{aligned}, \quad (11)$$

where $\alpha_{ij} = \alpha_{ji}, \forall i, j = \overline{1,3}; \quad t = \overline{1,T}$.

According to Arrow et al. (1961), the parameter $\alpha_0 = \ln a$ is the efficiency parameter, the parameters α_1, α_2, α_3 are the distribution parameters (scale), and the parameters α_{11}, α_{22}, α_{33}, α_{12}, α_{13}, α_{23} are the substitution parameters.

4. Results

4.1. Statistical analysis

Table 2 presents the values of the descriptive indicators specific to the variables analyzed.

Table 2. Descriptive statistics of variables (source: author's computation from Eviews 10 Output)

	RGDP	GFCF	REC	NREC
Max.	25.93000	8.020000	3.830000	30.72000
Min.	8.630000	1.110000	1.480000	15.03000
Std. Dev.	5.407095	2.231604	0.725935	3.364552
Prob.	0.259127	0.205341	0.263147	0.000001
Obs.	33	33	33	33

The maximum and minimum values of RGDP range between 8.63 thousand lei and 25.93 thousand lei, while GFCF ranges between 1.11 thousand lei and 8.02 thousand lei. On the other hand, the values for REC range between 1.48 thousand kWh and 3.83 thousand kWh, indicating a relatively narrow range of variation in renewable primary energy consumption per capita. The standard deviation for RGDP is 5.407, suggesting significant variability in the data regarding real gross domestic product per capita. The standard deviation for REC is 0.725, suggesting moderate variability in the data. To determine the direction of association between the variables, a correlation analysis will be performed (Table 3).

Table 3. Correlation matrix of the variables

Sample: 1990 2022				
Included observations: 33				
	RGDP	GFCF	REC	NREC
RGDP	1.000			
GFCF	0.962	1.000		
REC	0.853	0.779	1.000	
NREC	–0.643	–0.646	–0.708	1.000

As can be seen, the first two independent variables are positively correlated with the RGDP, the correlation between them being very strong, the Poisson ratio has the value 0.962 in the case of GFCF and strong in the case of REC (0.853). NREC is inversely correlated with RGDP, the correlation being of medium intensity (–0.643).

4.2. Unit roots and granger causality

To ensure the results obtained from modeling are accurate and reliable, it is necessary to verify the stationarity of the analyzed variables. For this, we will first determine the order of integration of each data series by applying the Argument Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test in both the constant and linear trend cases. The results obtained using the EViews program are included in the Table 4.

Table 4. The results obtained for the unit root test

	Constant		Constant. Linear Trend	
Variables	ADF	PP	ADF	PP
lnRGDP	–4.4005 (1) ***	–4.6436 (3) ***	–4.2576 (1) **	–4.3567 (3) **
D (lnRGDP)	–6.4325 (1) ***	–8.2464 (3) ***	–6.4205 (1) ***	–8.8037(3) ***
lnGFCF	–4.4510 (1) **	–5.7022 (3) ***	–4.3869 (1) **	–6.3462 (3) ***
D (lnGFCF)	–5.8148 (1) **	–15.0592 (3) ***	–5.6942 (1) ***	–14.3181 (3) ***
lnREC	–7.0140 (1) ***	–9.5052 (3) ***	–6.8913 (1) ***	–9.2543 (3) ***
D (lnREC)	–6.8054 (1) ***	–25.3656 (3) ***	–6.6882 (1) ***	–30.9183 (3) ***
lnNREC	–4.9636 (1) ***	–6.7720 (3) ***	–4.7728 (1) **	–6.2612 (3) ***
D (lnNREC)	–4.3969 (1) **	–12.2815 (3) ***	–4.4123 (1) **	–18.2609 (3) ***

Notes: ***, ** symbolized the significance at 1% level, the significance at 5% level. The tests are applied for 1st difference and Schwarz Info criterion. The parentheses () denote the optimal lag length and bandwidth.

Analyzing the results obtained above, we can conclude that for both ADF (Constant) and PP (Constant) tests, the null hypothesis is rejected, i.e., all the variables analyzed for Romania are stationary at the significance threshold of 1% and 5%, which means they do not have a unit root. This suggests that all variables are stationary at the first order I (1) difference. We can draw the same conclusion for the differentiated series of the analyzed variables, they are stationary at the significance threshold of 1%, respectively 5% for the differentiated variables D (lnGFCF) and D (lnNREC).

If the linear trend is also considered, all the variables analyzed for Romania are stationary at the significance threshold of 1%, respectively 5% (lnRGDP), which means that they do not have a unit root in the case of applying the PP test. In the case of the ADF test, the variable lnREC, respectively the differentiated variables D (lnGFCF) and D (lnREC) are stationary of order I (1), at the significance threshold of 1%, and the others are stationary of order I (1) for a threshold of 5% significance. Keeping the above in mind, we can next analyze whether there is a short-term causal relationship between the dependent variable and the three independent variables. For this we will apply the Pairwise Granger causality test (Table 5). This is useful to understand the dynamics and interdependencies between the independent variables that play the role of production factors in the CES model to be applied.

Table 5. Pairwise Granger causality tests

Sample: 1990 2022 Lags: 2			
Null Hypothesis:	Obs	F-Statistic	Prob.
lnRGDP does not Granger Cause lnGFCF	31	2.17788	0.1335
lnGFCF does not Granger Cause lnRGDP		2.21944	0.1288
lnRGDP does not Granger Cause lnNREC	31	2.50202	0.1014
lnNREC does not Granger Cause lnRGDP		3.72542	0.0378
lnRGDP does not Granger Cause lnREC	31	1.96084	0.1610
lnREC does not Granger Cause lnRGDP		0.57812	0.5680

Following the application of this test, we can conclude that only lnNREC has a causal relationship with lnRGDP in Romania. In the case of the other input variables, lnGFCF and lnREC, they do not show significant causal relationships, for any of the directions, with lnRGDP.

4.3. Estimation of CES models

The parameters of the two models, defined in relations (7) and (8) are estimated by the least squares method, the optimization method used is Gauss-Newton, the Marquardt steps (Gauss-Newton/Marquardt steps), convergence tolerance 0.0001. The Eviews 10.1 programs was used to estimate the parameters. The outcome can be seen in Table 6.

Table 6. The values of the coefficients of the two models

Dependent variable: LNRGDP- Model 1					Dependent variable: LNRGDP-Model 2				
	Coeff.	Std. Err.	t-Stat.	Prob.		Coeff.	Std. Err.	t-Stat.	Prob.
α_0	**23.474****	9.2029	2.5506	0.017	α_0	**–46.103*****	12.642	–3.6466	0.001
α_1	**2.4856*****	0.7393	3.3618	0.002	α_1	**0.8178***	0.5317	1.5381	0.138
α_2	**–9.3477****	3.4488	–2.7104	0.012	α_2	**–2.2244***	2.4277	–1.9162	0.369
α_3	**–12.699****	5.3410	–2.3776	0.026	α_3	**–4.5576***	3.5606	–1.2799	0.213
α_{11}	**–0.0719***	0.0499	–1.4407	0.163	α_{11}	**0.0108***	0.0337	1.3212	0.511
α_{22}	**0.3914***	0.4362	1.8973	0.378	α_{22}	**0.0099***	0.2771	1.0359	0.471
α_{33}	**1.8870****	0.7722	2.4433	0.022	α_{33}	**0.7931***	0.5099	1.5552	0.134
α_{12}	**0.4371****	0.2311	1.8913	0.071	α_{12}	**0.1473***	0.1506	1.9782	0.338
α_{13}	**–0.744*****	0.2131	–3.4947	0.002	α_{13}	**–0.251***	0.1542	–1.6344	0.116
α_{23}	**2.8344****	1.0105	2.8050	0.010	α_{23}	**0.7021***	0.7148	1.9821	0.336
–	–	–	–	–	*c*	**0.0274*****	0.0044	6.1648	0.000

Note: ***, ** and * symbolized the significance at 1% level, the significance at 5% level and the significance at 10%.

Analyzing the values of the parameters of the two models (which have the role of elasticities), we notice that the increase in REC by one percent, will lead to a decrease in RGDP by 9.34% (Model 1), respectively by 2.22% (Model 2), when the other independent variables are constant.

Also, the increase in NREC by 1% will lead to a decrease in RGDP by 12.69% (Model 1) and 4.55% (Model 2), respectively, when the other independent variables are constant. On the other hand, a 1% increase in GFCF is associated with a 2.48% (Model 1) and 0.81% (Model 2) increase in RGDP, respectively. Also, the influence exerted by the linear trend given by the time variable on the RGDP in Romania (Model 2) is insignificant, contributing to an increase of only 0.027%.

Also, Table 6 includes the values of the t-Student statistic, which is applied to test the significance of the parameters of the two analyzed models. Thus, the estimators of the two models can be considered significantly different from zero.

To validate the two models, from a statistical point of view, they must satisfy a number of assumptions. In order to check these assumptions, Table 7 shows the calculated values of those indicators that show us if the models analyzed above work well, based on which forecasts can be made later.

Table 7. Test results applied to the two models

	Model 1	Model 2		Model 1	Model 2
R^2	0.989990	0.996330	Mean dependent var	2.650127	2.650127
Adjusted R^2	0.986073	0.994662	S.D. dependent var	0.357993	0.357993
S.E. of regression	0.042247	0.026156	Akaike info criterion	–3.245517	–4.188306
Sum squared resid	0.041051	0.015051	Schwarz criterion	–2.792030	–3.689470
Log likelihood	63.55103	80.10705	Hannan-Quinn criter.	–3.092932	–4.020463
F-Statistic	252.7516	597.2727	Durbin-Watson stat	2.072628	2.170138
Prob(F-Statistic)	0.000000	0.000000	Jarque-Berra	1.071258	2.703782

Analyzing the data obtained in the table above, we can conclude that both models give very good results. If we compare the value of the adjusted determination ratio (relative indicator for measuring the strength of the link between the variables) it is observed that in the case of Model 2, it is higher, which tells us that the variables in the model together explain 99.63% of the total variation in growth economic per capita during the study period.

4.4. Robustness tests

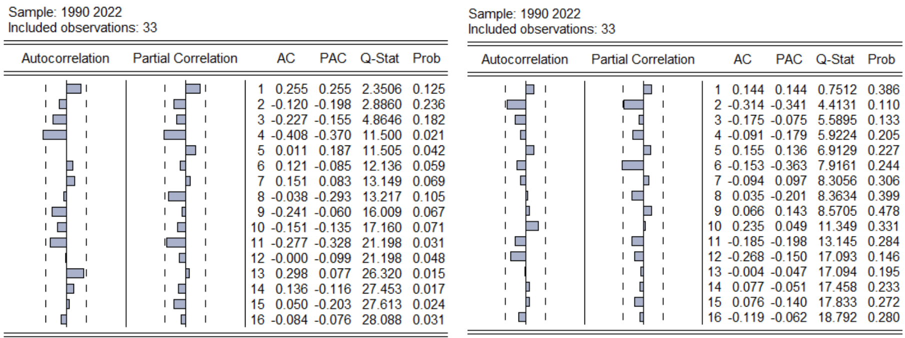
To ensure the validity and reliability of the obtained results, we applied a series of robustness tests. To observe whether at the level of the two models there is at least one input variable that influences the behavior of the output variable, the F test is used (Table 7).

Following the analysis, we can say that all the input variables have a significant influence on the output variable in the case of both analyzed models. The Jarque-Bera test is applied to check whether the residuals of the two models are normally distributed.

Comparing the values of this statistic to the critical value of the statistic $\chi^2_{3,0.05} = 7.815$ for a significance threshold $\alpha = 5\%$ and three degrees of freedom, respectively $\chi^2_{4,0.05} = 9.488$, for a significance threshold $\alpha = 5\%$ and four degrees of freedom, it is observed that the inequality $JB < \chi^2$ is checked for both models.

In order to detect heteroscedasticity, the Breusch-Pagan-Godfrey test is applied through statistic $LM = n \cdot R^2$, the value of which is 3.89 (Model 1), respectively 0.75 (Model 2).

By checking the inequality $LM < \chi^2$ for a significance threshold by 5% and three, respectively, four degrees of freedom, it is observed that the variance of the residual is constant within both analyzed models.



Sample: 1990 2022
Included observations: 33

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.255	0.255	2.3506	0.125
		2	-0.120	-0.198	2.8860	0.236
		3	-0.227	-0.155	4.8646	0.182
		4	-0.408	-0.370	11.500	0.021
		5	0.011	0.187	11.505	0.042
		6	0.121	-0.085	12.136	0.059
		7	0.151	0.083	13.149	0.069
		8	-0.038	-0.293	13.217	0.105
		9	-0.241	-0.060	16.009	0.067
		10	-0.151	-0.135	17.160	0.071
		11	-0.277	-0.328	21.198	0.031
		12	-0.000	-0.099	21.198	0.048
		13	0.298	0.077	26.320	0.015
		14	0.136	-0.116	27.453	0.017
		15	0.050	-0.203	27.613	0.024
		16	-0.084	-0.076	28.088	0.031

Sample: 1990 2022
Included observations: 33

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.144	0.144	0.7512	0.386
		2	-0.314	-0.341	4.4131	0.110
		3	-0.175	-0.075	5.5895	0.133
		4	-0.091	-0.179	5.9224	0.205
		5	0.155	0.136	6.9129	0.227
		6	-0.153	-0.363	7.9161	0.244
		7	-0.094	0.097	8.3056	0.306
		8	0.035	-0.201	8.3634	0.399
		9	0.066	0.143	8.5705	0.478
		10	0.235	0.049	11.349	0.331
		11	-0.185	-0.198	13.145	0.284
		12	-0.268	-0.150	17.093	0.146
		13	-0.004	-0.047	17.094	0.195
		14	0.077	-0.051	17.458	0.233
		15	0.076	-0.140	17.833	0.272
		16	-0.119	-0.062	18.792	0.280

Figure 2. Q-statistic correlogram (left Model 1, right Model 2)

To check if there is an autocorrelation effect between the variables observed in the two models, the Q-Statistic correlogram is performed (Figure 2).

As can be seen, the residual series for the two models are not affected by the autocorrelation phenomenon. This hypothesis can also be verified by the Durbin-Watson statistic, whose value can be found in Table 6 for both models. An important problem faced by multivariable models is the presence of multicollinearity at the level of exogenous variables. To check if there is multicollinearity between the variables analyzed in this study, the variance inflation factor analysis is applied. Table 8 shows the values of the inflation factor calculated for both analyzed models.

Table 8. Variance inflation factors

Model 1		Model 2	
Variable	Coeff. variance	Variable	Coeff. variance
α_0	4.69517	α_0	1.8403
α_1	0.54666	α_1	0.28271
α_2	1.89431	α_2	5.89416
α_3	2.52694	α_3	1.67838
α_{11}	0.00249	α_{11}	0.00113
α_{22}	0.19034	α_{22}	0.07678
α_{33}	0.59643	α_{33}	0.26009
α_{12}	0.05343	α_{12}	0.02269
α_{13}	0.04542	α_{13}	0.02379
α_{23}	1.02113	α_{23}	0.51103
–	–	*c*	1.99E-05

It is appreciated that a value greater than five of the inflation factors signals the presence of the multicollinearity phenomenon. As all the values are lower than five, we can say that none of the models presents the phenomenon of multicollinearity.

To verify the stability of the parameters of the two analyzed models, the Cumulative Sum test (CUSUM) is used. By applying this test, the presence of outliers within the data series is also emphasized and the structural breaks within these series are highlighted. Figure 3 shows the CUSUM test for both *Model 1* and *Model 2*.

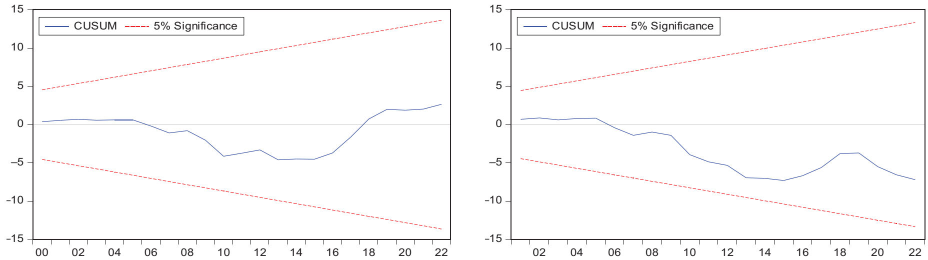


Figure 3. CUSUMSQ test to check the stability of the parameters of the two models (left Model 1, right Model 2)

Since the 5% line lies within the upper and lower bounds, we can say that the parameter estimates of the two models are stable.

5. Choosing the best performing model

In order to choose which of the two models performs better, a series of indicators is calculated. Thus, in Table 9, the values of the standard deviation, the average linear deviation, the Bias proportion, and the coefficient of variation for both models are calculated with the help of the Eviews 10.1 program.

Table 9. Descriptive indicators for measuring the quality of models

	Model 1	Model 2
Root mean squared error	0.035	0.021
Mean absolute error	0.030	0.016
Mean absolute procent error	1.148	0.618
Theil inequality coefficient	0.006	0.003
Bias proportion	0.000	0.000
Variance proportion	0.002	0.0009

The best performing model is the one for which the values of the indicators entered in Table 8 are lower (closer to zero). Therefore, it can be easily seen that the second model gives better results than the first model (the one without technical progress).

The same conclusion is reached if we analyse the values of the three criteria that are based on information theory (Akaike, Schwarz and Hannan-Quinn). In the case of model 2, the values of the three criteria are lower, therefore the model in which technical progress is also taken into account gives better results. If we employ the actual values and the values adjusted by the CES functions with and without technical progress, we will reach the same conclusion (Figure 4). Also, the errors between the real values and the values estimated by the two models are highlighted for the last three years.

It can be seen that the curve represented by Model 2 is almost confused with the curve given by the real values of lnRGDP. In conclusion, we recommend that Model 2 be used for forecasting, the one in which the linear trend of RGDP is taken into account. To interpret the results obtained by applying the CES function without technical progress (Model 1) and with technical progress (Model 2), we will determine the parameters of the CES function, defined in relations (4) and (5), by using relations (7)–(9) (Table 10).

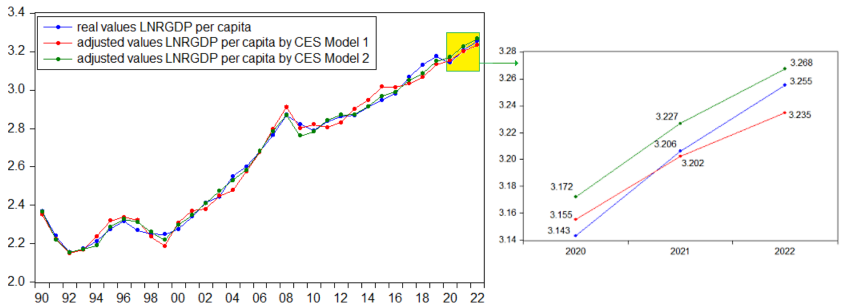


Figure 4. Representation of real values of RGDP in Romania in logarithmic terms (blue), values adjusted by the CES function without trend (red) and values adjusted by the CES function with trend (green)

Table 10. Parameter estimation by the three-input CES function

Parameters	Values model 1	Values model 2
a	9.47**	$9.49 \cdot 10^{-21***}$
β_1	-0.127^{**}	-0.137^{***}
β_2	0.478^{**}	0.373^{***}
β_3	0.649^{**}	0.764^{***}
ξ	1.155^{**}	0.678^{**}

Note: ***, ** indicates that the parameter is significantly different from zero at the 1% level, and at the 5% level.

Following the results obtained, the value of the scale parameter is lower than the unity, in both cases, this highlighting the fact that the CES-type production function has decreasing returns to scale, i.e., a specified increase in GFCF, of REC and NREC, leads to an increase in RGDP in a smaller proportion. Practically, the economic growth per capita in Romania, effect of the evolution of the three variables, is inefficient. In another train of thoughts, the overall efficiency of the factors observed in this study is positive in both cases analyzed. The substitution parameter ξ of the factors participating in the analyzed process is greater than one in the first model and less than zero in the second model.

The elasticity of factor substitution is greater than zero in both cases analyzed. So, for Model 1: σ = 0.464 and for Model 2: σ = 0.596. In both models, the elasticity of substitution is less than unity, which reflects the absence of large productivity differences between the three factors of production analyzed. To better understand the robustness of the results, we will measure the technical efficiency of the inputs, more specifically GFCF, REC and NREC, relative to output, which is RGDP.

Even if the analysis is carried out only for Romania, for this we will apply an SFA model (Stochastic Frontier Analysis), which is an econometric model that separates technical inefficiency from random shocks. This model is useful for assessing how efficiently inputs are used relative to lnRGDP. For a CES function using the TRANSLOG method, the SFA model is defined by the relation:

$$\begin{aligned}\ln RGDP_t &= \ln a + \alpha_1 \ln GFCF_t + \alpha_2 \ln REC_t + \alpha_3 \ln NREC_t + \\ &\alpha_{11}\left(\ln GFCF_t\right)^2 + \alpha_{22}\left(\ln REC_t\right)^2 + \alpha_{33}\left(\ln NREC_t\right)^2 + \\ &\alpha_{12} \ln GFCF_t \cdot \ln REC_t + \alpha_{13} \ln GFCF_t \cdot \ln NREC_t + \alpha_{23} \ln REC_t \cdot \ln NREC_t + v_t - u_t,\end{aligned} \tag{12}$$

where v_t represents the random error (capturing random shocks) and are assumed to be normally distributed with mean zero and variance σ_v^2, and u_t represents the technical inefficiency error (capturing inefficiencies in the use of resources) and are assumed normally distributed with mean μ and variance σ_u^2.

The values of the parameters of the SFA model were estimated using the least squares method and can be found in the Table 11. The results were processed in the Matlab program (Nguyen et al., 2022). Technical efficiency is calculated with the relation:

$$TE_t = e^{-u_t}. \tag{13}$$

If $u_t = 0$ și $TE_t = 1$, the models output equals maximum yield and is in the state of efficiency. If $u_t > 0$ and $0 < TE_t < 1$ it indicates that the output is less than the maximum output and exists in the state of inefficiency.

Table 11. Results of estimation of the Stochastic Frontier Analysis (SFA) (source: authors' computation from Matlab)

Dependent variable: lnRGDP				
Variable	Coeff.	Std. Error	t-Statistic	Prob.
α_0	6.5071**	11.4309	0.5692	0.0574
α_1	3.6093***	0.8501	4.2456	0.0009
α_2	–9.841***	3.1947	–3.0805	0.0054
α_3	–1.3192*	7.1138	–0.1854	0.0854
α_{11}	–0.0264*	0.0505	–0.5232	0.0606
α_{22}	0.2737**	0.4066	0.6730	0.0507
α_{33}	–0.0247*	1.118	–0.0220	0.0982
α_{12}	0.4335*	0.2136	2.0295	0.0546
α_{13}	–1.172***	0.2754	–4.2569	0.0003
α_{23}	3.090***	0.9409	3.2842	0.0034

Note: ***, ** and * symbolized the significance at 1% level, the significance at 5% level and the significance at 10%.

Figures 5 shows the evolution over time of technical efficiency. Most observations record values equal to unity, indicating an efficient use of resources.

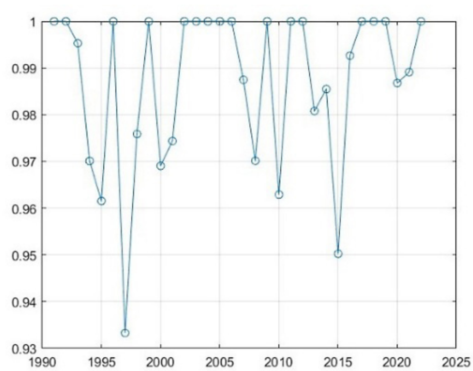


Figure 5. The evolution of technical efficiency in Romania

Logging observations with values less than 1 suggests technical inefficiency. For example, the observation with the technical efficiency of 0.9333 is one of the most inefficient in the data set (1995). In the case of Romania, these inefficiencies can be caused by factors such as insufficiently developed infrastructure, low level of investment in modern technologies, ineffective management or limited access to finance.

6. Discussions

Starting from the inconsistency of the existing results in the specialized literature that analyzed the contribution of renewable and non-renewable primary energy consumption, and of the gross capital formation to the economic growth, the current study is aimed to examine the nature of this relationship in the case of Romania over a period of 33 years (1990–2022). For this, it is used an econometric model based on a CES function, followed by an analysis of the unit roots and causality test. The analysis of the correlation and a verification of the stability of the parameters of the two models based on the Cumulative Sum test, allowed to highlight a negative contribution of renewable and non-renewable primary energy consumption on economic growth, while the gross capital formation contributes positively to economic growth. A similar approach aimed at investigating the consumption of different types of energy on Romania's economic growth belongs to Rehman et al. (2022). While the analysis period overlaps the one considered in the present study and the investigation method differs, but the results obtained confirm the present outcomes.

Previously, Sahlian et al. (2021) point out that in the short term "the dynamics of renewable energy consumption and gross domestic product are independent". Additionally, Simionescu et al. (2019) argue that the lack of causality is due to low levels of energy production from RES unable to ensure long-run economic welfare. In this case, the argument underlying the manifestation of such a relationship may be the low level of renewable energy consumption, which induces a negative effect on economic growth (Chen et al., 2020; Wang & Wang, 2020), this effect becoming positive only when a certain level of threshold is reached by renewable energy consumption (Amri, 2017).

As in this case, Emir and Bekun (2019) identified a causal relationship between renewable energy consumption and economic growth in Romania in research carried out during the period between 1990 and 2014. However, the results obtained are in contradiction with those of the present study.

If one considers the findings related to the negative impact of NREC on RGDP with 12.69% Model 1 and 4.55% Model 2, similar results were obtained by Yang et al. (2022) in an analysis of nine Eastern African nations between 1980 and 2017 or by Awodumi and Adewuyi (2020), in the case of Nigeria or Bouyghrissi et al. (2021) for Morocco. The authors stating that the outcomes were justified by this country's dependence on energy imports. For Wang et al. (2022), analysis of the effect generated by fossil fuel energy usage on GDP in Pakistan leads them to conclude that although at first the increase in consumption causes a rise in the level of output per capita, continued reliance on fossil fuel energy eventually begins to harm per capita output in the long term.

Even if the outcomes confirm the existence of a negative influence exerted by REC and NREC on RGDP (9.34% Model 1, and 2.22% Model 2), we consider that it is likely to reveal low levels of consumption unable to influence economic growth. Against the background of the already proven advantages of the green economy, we believe that, under these circumstances, decision-makers' efforts must continue to foster the expansion of renewable energy consumption, thus contributing to an efficient management of energy and environmental policies, economic growth and development.

7. Conclusions

There is no doubt that sustaining economic growth is conditional on energy consumption. Even if we are currently witnessing greater or smaller changes in the energy mix of the world's states, amidst an increasing importance paid to environmental protection, energy generation and consumption remain priorities, the current challenges being related to the way they are provided from clean or unclean energy sources.

Considering that renewable resources have been accepted as a solution in ensuring energy supply related to global/national/regional sustainable development, the focus of both researchers and governments and institutions has been aimed at managing climate change towards finding the most efficient ways to stimulate and ensure the production of renewable energy, as well as shaping economic and individual behaviors in order to increase the consumption of renewable energy. Romania is one of the countries which has developed and implemented a series of regulations designed to support the gradual transition from fossil fuel-based energy production and consumption to green energy, without ensuring environmental protection at the expense of economic growth. Although, being on an upward trend, the renewable energy consumption does not yet have the 'power' to take over the "attributions" that belonged to the non-renewable energy consumption in ensuring economic growth, so the concerns of the policy makers must focus not only on changing consumption patterns and continuing the decrease non-renewable energy consumption, but also on reaching levels of renewable energy consumption capable of favorably impacting GDP growth per capita.

The current study is based on these coordinates which are capable of offering evidence on the impact of GFCF, REC and NREC on the economic growth in Romania over 33 years (1990–2022), highlighting the significant and positive contribution of capital formation, but also the low levels of renewable energy consumption, i.e., non-renewables, unable to generate GDP growth. The results of the study thus lead to the recommendation addressed to policy makers to consider adopting strategies aimed at increasing energy efficiency, implementing energy saving projects and stimulating renewable energy consumption.

A limitation of this study derives from the consideration of the impact of the REC and NREC on economic growth only with regard to Romania. Due to the fact that the results obtained are confirmed and at the same time refuted by a series of other researches that had either the same subject of analysis or the same country, the authors consider the prospect of broadening the research in terms of expanding the number of countries observed. Obviously, analyzing only the contribution of REC and NREC and GFCF to economic growth are considered limitations of the study. Another limitation concerns the investigation method so that for future research, authors consider choosing different methods and econometric models to analyze causality between variables, in order to get additional information which confirms or contradicts the present results.

Author contributions

DN and NS conceived the study and were responsible for the design and development of the data analysis. NS was responsible for data collection and analysis. DN and NS were responsible for data interpretation. ND wrote the first draft of the article. All authors read and approved the final manuscript.

Disclosure statement

Authors do not have any competing financial, professional, or personal interests from other parties.

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