The impact of energy demand on economic growth: A new empirical evidence for Madagascar

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Abstract

This study investigates the impact of energy demand on Madagascar's economic growth from 2007Q1 to 2022Q4. Drawing upon a rich dataset from Malagasy sources, we applied the ARDL bounds testing approach and found cointegration among the series. We found that, in the long run, electricity and petroleum consumption have positive significant effects on economic growth, while energy imports and global prices have negative significant effects. We further applied Granger-causality test based on Error Correction Model to examine causal relationships. The results revealed that in the short run, there are unidirectional causal effects running from electricity consumption, energy imports, and global prices to economic growth. The test also revealed that both energy demand and global prices have a long-run causal effect on economic growth. Our findings confirms that Madagascar is an energy-dependent economy, and provide valuable insights for policymakers to design effective energy policies that promote economic growth and energy security.

Keywords: energy demand, electricity consumption, petroleum consumption, energy imports, economic growth, Madagascar

1 Introduction

Statistical data related to energy in Madagascar generally focuses on electricity and petroleum (INSTAT, 2022b). While the "Energy and Growth" theme is popular among Malagasy economists and scholars, research addressing the impact of energy demand on economic growth within Madagascar remains scarce. This scarcity extends to studies utilizing primary data from Malagasy authorities, likely due to limited public access. To the best of our knowledge, only a handful of publications like Voninirina & Andriambelosoa (2014) and Andriamanga (2017) have empirically examined this relationship using Malagasy data. Recognizing this gap, our study presents a renewed empirical assessment of the impact of energy demand on economic growth in Madagascar. The originality of this study lies in its exclusive use of primary data from relevant Malagasy authorities. We apply the Autoregressive

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Distributed Lag (ARDL) bounds testing approach to comprehensively analyze the dynamic relationship between energy consumption and economic growth in Madagascar based on quarterly data from 2007Q1 to 2022Q4. Additionally, we employ Granger-causality tests based on an error correction model to comprehensively reassess the causal relationship between these variables, previously explored by Voninirina & Andriambelosoa (2014) and Andriamanga (2017).

2 Brief empirical review

Initially, Voninirina & Andriambelosoa (2014) conducted an econometric analysis to investigate the relationship between energy consumption and economic growth in Madagascar. Their research aimed to discern the existence of a long-term relationship between economic growth and energy consumption, using annual data from 1980 to 2011 (retrieved from the World Bank's World Development Indicators and JIRAMA) and applying cointegration methodology. They used Granger's method to determine the direction of the relationship during the same period. Their findings revealed the lack of a long-term relationship between the variables, however, they identified a bidirectional causality relationship. Later, Andriamanga (2017) investigated the empirical relationship between energy consumption and economic growth in Madagascar for the 1995–2015 period. The data sources include annual statistics from the World Bank, and the former Ministry of Water, Energy, and Hydrocarbons. The empirical methodology was conducted through the Error Correction Model (ECM) framework to analyze the short and long-term dynamics. In contrast to Voninirina & Andriambelosoa (2014)'s results, Andriamanga (2017)'s findings revealed a significant long-term relationship between energy consumption (electricity and petroleum) and economic growth. Additionally, bidirectional Granger causality between petroleum consumption and economic growth was identified, as well as unidirectional Granger causality running from electricity consumption to economic growth.

It is also worth noting the empirical results which were conducted in the context of panel data analysis. Nondo et al. (2010) conducted panel cointegration techniques and panel causality tests on a group of 19 African countries within the Common Market for Eastern and Southern Africa (COMESA). The tests, based on data spanning from 1980 to 2005, revealed that energy consumption (proxied by BTU of energy) stimulates GDP growth, in the short and long run for low-income countries in COMESA. In contrast, Kahsai et al. (2012) tested the relationship between energy consumption and economic growth in Sub-Saharan African countries, using a panel co-integration approach for 40 countries for the 1980–2007 period, and their findings support the neutrality hypothesis in the short-run, i.e., no causality between energy consumption and economic growth in the short-run. However, they find a bidirectional interdependence of energy consumption and economic growth in Sub-Saharan Africa in the long run. In addition, Karanfil & Li (2015) used a panel of 160 countries for the 1980–2010 period to examine the long- and short-run dynamics between electricity consumption and economic activities. Specifically, they used panel cointegration techniques to estimate the relationship between electricity consumption, real GDP, electricity net imports, and urbanization ratio. They identified a bidirectional short-run causality between electricity consumption and real GDP for low-income countries. Later, Atems & Hotaling (2018) assessed the impact of electricity generation instead of electricity consumption, considering the fact that not all of the electricity generated in a country is eventually consumed because of transmission and distribution losses, as well as theft. Therefore, they investigated the impact of total electricity generation on economic growth, disentangled into renewable and non-renewable effects, using data from a panel of 174 countries over the period 1980 to 2012, and using the System Generalized Methods of Moments approach. Their results indicate a positive relationship between renewable and nonrenewable electricity generation and economic growth. Similarly, Espoir et al. (2023) investigated the impact of renewable electricity consumption (REC) and non-renewable electricity consumption (NREC) on economic growth in 51 African countries between 1980 and 2018. They found that NREC has a positive impact on economic growth but surprisingly, the effect of REC is negative in the COMESA region. Moreover, they find that both REC and NREC have positive effects on growth in the Southern African Development Community (SADC) region. Recently, Mmbaga et al. (2023) examined the relationship between energy consumption and economic growth in the East African sub-region (2012-2021). They employed panel data from 13 countries and used Pooled Ordinary Least Squares, Fixed Effects, and Generalized Method of Moments. Their findings suggest that both higher energy prices and increased energy consumption reduce economic growth, highlighting the need for careful energy management in this developing region.

3 Data and methodology

3.1 Data descriptions

Data used in this study are mainly obtained from the National Institute of Statistics (INSTAT), the Malagasy Office of Hydrocarbons (OMH), the Jiro sy Rano Malagasy (JIRAMA)–the national water and electricity company of Madagascar, and the General Directorate of Customs (Douane Malagasy) within the Ministry of Economy and Finance. Our empirical estimation is based on quarterly observations that cover the period 2007Q1 to 2022Q4. Data are summarized in Table 1.

Table 1: Variable definition.

Variables	**Notation**	**Description (unit)**	**Source**
Economic growth	*GDP*	Real gross domestic product (billions of Ariary, at 2007 constant prices)	INSTAT
Electricity consumption	*ELEC*	Sum of low and medium voltage electricity consumption (GWh)	JIRAMA; INSTAT
Petroleum consumption	*PETRC*	Sum of naphtha, jet fuel, aviation fuel, liquefied petroleum gas, kerosene, super-unleaded petrol, gasoline, gas oil, and heavy fuel oil consumption (cubic meter)	OMH; INSTAT
Energy imports	*ENRMG*	Sum of imports of petroleum products and other fuel products (% total volume of imports of goods)	Douane Malagasy; INSTAT
Global prices	*CPI*	Consumer price index (2016 = 100)	INSTAT

The following descriptions provide a concise overview of the variables used in our analysis. Unless otherwise indicated, the reported shares represent averages from 2007Q1 to 2022Q4.

- Madagascar's quarterly GDP at constant 2007 prices are taken from the INSTAT quarterly national accounts which provide information consistent with annual national accounts. The quarterly GDP allows better responsiveness to economic shocks and for short-term monitoring of economic policies (INSTAT, 2019a). As of the 2007 base year, Madagascar's GDP splits across primary (28.1%), secondary (10.9%), and tertiary (54.5%, including Financial intermediation services indirectly measured) sectors, with the remaining 6.5% attributed to indirect taxes (INSTAT, 2019b).

- The JIRAMA manages the distribution of electricity at two distinct voltage levels. Low voltage caters to the needs of households and public lighting (61.6%), while medium voltage serves the demands of the three major economic sectors: primary (0.3%), secondary (24.9%), and tertiary (13.2%). As of 2021, 45.2% of the JIRAMA's electricity is generated from renewable sources (95.6% of which comes from hydropower plants), with the remaining 54.8% generated by thermal power plants running on heavy fuel oil and gas oil (ARCEB, 2022, p. 53).

- According to data from the petroleum market monitored by the OMH, petroleum products consist of naphtha, liquefied petroleum gas (LPG), aviation fuel, jet fuel, super-unleaded petrol, gasoline, kerosene, gas oil, and heavy fuel oil. These products are distributed across various sectors of activity, including transportation, aviation, bunkers (maritime operations), the JIRAMA, Ambatovy and QIT Madagascar Minerals (QMM)–two of Madagascar's major mining companies–households and industries, and construction projects (OMH, 2023a). Based on available data ranging from 2016 to 2022, transportation has the largest share among all sectors (about 50.0%), primarily consuming gas oil and super-unleaded petrol (OMH, 2023c). The second largest consumer is the JIRAMA, accounting for roughly 21.8% of petroleum products. Households and industries together claim approximately 10% of the share. Households primarily utilize LPG for cooking, and kerosene for lighting and cooking, especially in rural areas (Naidoo & Loots, 2020). Meanwhile, industries rely on gasoline for vehicles, gas oil for generators and machinery, and heavy fuel oil for specific processes.

- Madagascar's imports of goods can be categorized into five main groups: food, energy, equipment, raw materials, and miscellaneous items. Raw materials represent the dominant category, accounting for nearly half of all imports. Energy follows closely, constituting a significant quarter of the total volume imports of goods. Within the energy category, according to the Harmonized System (HS) classification, coal and petroleum oils are the primary imports. For example, as of 2022, the main energy imports consist of selected sub-items for the following classification.

  - **HS2701** Coal; briquettes, ovoids and similar solid fuels manufactured from coal.
  - **HS2703** Peat, incl. peat litter, whether or not agglomerated.
  - **HS2704** Coke and semi-coke of coal, of lignite or of peat, whether or not agglomerated; retort carbon.
  - **HS2707** Oils and other products of the distillation of high temperature coal tar; similar products in which the weight of the aromatic constituents exceeds that of the non-aromatic constituents.
  - **HS2710** Petroleum oils and oils obtained from bituminous minerals (excl. crude); preparations containing >= 70% by weight of petroleum oils or of oils obtained from bituminous minerals, these oils being the basic constituents of the preparations, n.e.s.; waste oils containing mainly petroleum or bituminous minerals.
  - **HS2711** Petroleum gas and other gaseous hydrocarbons.
  - **HS2713** Petroleum coke, petroleum bitumen and other residues of petroleum oil or of oil obtained from bituminous minerals, n.e.s.
  - **HS4401** Fuel wood, in logs, billets, twigs, faggots or similar forms; wood in chips or particles; sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms.
  - **HS4402** Wood charcoal, incl. shell or nut charcoal, whether or not agglomerated (excl. wood charcoal used as a medicament, charcoal mixed with incense, activated charcoal and charcoal in the form of crayons).

  Note that data are sourced from the Douane Malagasy (2023) and consolidated with that of the International Trade Centre (ITC)'s Trade Map (`https://www.trademap.org/`).

- Consumer Price Index (CPI) data in Madagascar, compiled by INSTAT, uses the 2016 reference year as its basis and is referred to as the new CPI (INSTAT, 2019c). Within this new CPI, energy products hold a 7.8% share of the overall index. However, when categorized by function, the impact of energy is even more pronounced. Housing, water, electricity, gas, and other combustibles occupy a 20.3% share of the total CPI, suggesting that energy costs contribute to a substantial portion of household expenses in Madagascar (AfDB, 2023).

3.2 Empirical methodology

In this study, we applied the TRAMO/SEATS procedure (Gómez & Maravall, 1997) to remove seasonal and random fluctuations from the initial series of data. We then take *GDP*, *ELEC*, *PETRC*, and *ENRMG* variables in their natural logarithmic form. Next, we conduct unit root tests to justify that the variables are stationary at level, i.e., I(0), or at the first difference, i.e., I(1). We check stationarity through the Augmented Dickey-Fuller (ADF), Philips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests (Dickey & Fuller, 1979; Phillips & Perron, 1988; Kwiatkowski et al., 1992).

After determining the stationarity of the variables, we used the Autoregressive Distributed Lag (ARDL) bounds testing approach developed by Pesaran & Shin (1999) and Pesaran et al. (2001) to examine the impact of energy demand on economic growth in Madagascar. We build our model based on the availability of data and the empirical works of Alnour (2021), Choi & Yoo (2016), Gbadebo & Okonkwo (2009), Ghosh (2009), Kwakwa (2012), Murshed et al. (2020), Narayan & Singh (2007), Ngoc (2019), Odhiambo (2009), Okey (2009), Onakoya et al. (2013), Sama & Tah (2016). The functional relationship of our model, which we assume linear, then takes the following form:

$$GDP_t = f(ELEC_t, PETRC_t, ENRMG_t, CPI_t), \tag{1}$$

where variables are defined in Table 1. In (1), *ENRMG* is considered as a proxy for Madagascar's energy dependence, and *CPI* serves as a price level index, reflecting changing energy prices and integrating them into the dynamic relationship between energy consumption and its economic impact (Hondroyiannis et al., 2002; Kahsai et al., 2012; Mmbaga et al., 2023). The ARDL representation of (1), denoted ARDL$(p_1, p_2, p_3, p_4, p_5)$, takes the following form:

$$GDP_t = \beta_0 + \sum_{i=1}^{p_1} \beta_{1,i} GDP_{t-i} + \sum_{i=0}^{p_2} \beta_{2,i} ELEC_{t-i} + \sum_{i=0}^{p_3} \beta_{3,i} PETRC_{t-i} + \sum_{i=0}^{p_4} \beta_{4,i} ENRMG_{t-i} + \sum_{i=0}^{p_5} \beta_{5,i} CPI_{t-i} + \varepsilon_t,$$

where $(p_1, p_2, p_3, p_4, p_5)$ are the optimal lag length of the respective variables which are determined by the Hannan–Quinn information criterion (HQC), β_0 is a constant, the $\beta_{j,i}$'s represent the coefficients of the model, and ε_t is the usual white noise residuals.

The ARDL bounds testing approach is applicable irrespective of whether the variables are I(0) or I(1). It is appropriate for estimating both the short- and long-run coefficients, and selecting different lag lengths to address the endogeneity and serial correlation problems. Moreover, it encompasses the estimation of an unrestricted error-correction model which can be expressed as

$$\begin{aligned} \Delta GDP_t = \beta_0 &+ \sum_{i=1}^{p_1-1} \beta'_{1,i} \Delta GDP_{t-i} + \sum_{i=0}^{p_2-1} \beta'_{2,i} \Delta ELEC_{t-i} + \sum_{i=0}^{p_3-1} \beta'_{3,i} \Delta PETRC_{t-i} \\ &+ \sum_{i=0}^{p_4-1} \beta'_{4,i} \Delta ENRMG_{t-i} + \sum_{i=0}^{p_5-1} \beta'_{5,i} \Delta CPI_{t-i} + \alpha_1 GDP_{t-1} + \alpha_2 ELEC_{t-1} \\ &+ \alpha_3 PETRC_{t-1} + \alpha_4 ENRMG_{t-1} + \alpha_5 CPI_{t-1} + \varepsilon_t, \end{aligned} \tag{2}$$

where Δ denotes the first-difference operator, and the β' coefficients represent the short-run relationships, while the α coefficientd represent the long-run relationships. To examine a potential cointegrated relationship between variables, the null hypothesis of no cointegration

$$(H_0): \ \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0,$$

is tested against the alternative hypothesis of cointegration

$$(H_1): \ \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$$

through the F-statistic (Wald test). The F-statistic obtained from the bounds test is usually compared with the lower and upper bound values proposed by Pesaran et al. (2001). However, in the case of a small sample, as is our case, we use Narayan (2005)'s critical values to determine any long-term association among the variables. The lower critical bound assumes all the variables are I(0), meaning that there is no cointegration relationship between the examined variables. The upper bound assumes that all the variables are I(1), meaning that there is cointegration among the variables. If the computed F-statistic is greater than the upper bound critical value, then (H_0) is rejected. If the F-statistic is below the lower bound critical value, then (H_0) cannot be rejected. If the computed F-statistics falls between the lower and upper bound, then the results are inconclusive. If the variables are cointegrated, the long-run coefficients of each variable can be estimated through an error correction model:

$$\begin{aligned}\Delta GDP_t = \beta_0 &+ \sum_{i=1}^{p_1-1} \beta'_{1,i}\Delta GDP_{t-i} + \sum_{i=0}^{p_2-1} \beta'_{2,i}\Delta ELEC_{t-i} + \sum_{i=0}^{p_3-1} \beta'_{3,i}\Delta PETRC_{t-i} + \sum_{i=0}^{p_4-1} \beta'_{4,i}\Delta CPI_{t-i} \\ &+ \sum_{i=0}^{p_5-1} \beta'_{5,i}\Delta ENRMG_{t-i} + \varphi ECT_{t-1} + \varepsilon_t,\end{aligned}$$

where ECT_{t-1} stands for the one-period lagged error-correction term, which is the residuals that are obtained from the estimated cointegration model of (2), and φ denotes the measure for the speed of adjustment at which any distortion from the long-run equilibrium in the previous period is restored in the current period.

The stability of the ARDL estimates is then evaluated using a set of diagnostic tests. The normality of the residuals is evaluated using the Jarque-Bera test. The Breusch-Godfrey Lagrange multiplier (LM) test is used to explore the serial correlation problems. We diagnose the heteroskedasticity issues with the Breusch-Pagan-Godfrey heteroskedasticity and Autoregressive Conditional Heteroskedasticity (ARCH) tests. The correct functional form of the models is assessed using the Ramsey Regression Specification Error Test (RESET). Finally, the structural stability of the ARDL estimates is checked using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ) tests advanced by Brown et al. (1975).

Furthermore, we used the Granger-causality method to explore the causal interaction among the investigated variables. To achieve this, we run the pairwise Granger-causality tests and the Vector Error Correction Model (VECM) for the short- and long-run relationships, respectively (Engle & Granger, 1987). The estimate of the dynamic VECM is given as follows:

$$\Delta \boldsymbol{Y}_t = \boldsymbol{B}_0 + \sum_{i=1}^{\ell} \boldsymbol{B}_i \Delta \boldsymbol{Y}_{t-i} + \Phi ECT_{t-1} + \Lambda_t, \tag{3}$$

with

$$\boldsymbol{Y}_t = \begin{bmatrix} GDP_t \\ ELEC_t \\ PETRC_t \\ ENRMG_t \\ CPI_t \end{bmatrix}, \ \boldsymbol{B}_0 = \begin{bmatrix} \beta_{0,1} \\ \beta_{0,2} \\ \beta_{0,3} \\ \beta_{0,4} \\ \beta_{0,5} \end{bmatrix}, \ \boldsymbol{B}_i = \begin{bmatrix} \beta_{1,1,i} & \beta_{1,2,i} & \beta_{1,3,i} & \beta_{1,4,i} & \beta_{1,5,i} \\ \beta_{2,1,i} & \beta_{2,2,i} & \beta_{2,3,i} & \beta_{2,4,i} & \beta_{2,5,i} \\ \beta_{3,1,i} & \beta_{3,2,i} & \beta_{3,3,i} & \beta_{3,4,i} & \beta_{3,5,i} \\ \beta_{4,1,i} & \beta_{4,2,i} & \beta_{4,3,i} & \beta_{4,4,i} & \beta_{4,5,i} \\ \beta_{5,1,i} & \beta_{5,2,i} & \beta_{5,3,i} & \beta_{5,4,i} & \beta_{5,5,i} \end{bmatrix}, \ \Phi = \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \end{bmatrix}, \ \Lambda_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \\ \varepsilon_{3,t} \\ \varepsilon_{4,t} \\ \varepsilon_{5,t} \end{bmatrix},$$

where $\boldsymbol{B}_0$ is a constant vector, $\boldsymbol{B}_i$ is a matrix of the coefficients that need to be estimated and which will demonstrate the short-run causality across the variables, Φ is a vector of the coefficients of the one-period lagged error-correction term (ECT_{t-1}) which indicates the adjustment of the dependent variables to their long-run equilibrium, and Λ_t is a vector of the white noise residuals. The optimal lag length ℓ in (3) is selected using the Schwarz's Bayesian information criterion (BIC).

The advantage of using an error-correction model to test for causality is that it allows testing for short-run causality through the lagged difference explanatory variables and for long-run causality through the lagged error-correction term. On the one hand, short-run Granger-causality is examined by testing (H_0): $\beta_{i,j,1} = \beta_{i,j,2} = \beta_{i,j,3} = \cdots = \beta_{i,j,\ell} = 0$, using Wald test's F-statistics, where $i, j = 1, \ldots, 5$, with $i \neq j$. For example, $\beta_{1,2,1} = \beta_{1,2,2} = \beta_{1,2,3} = \cdots = \beta_{1,2,\ell} = 0$ indicates that electricity consumption does not Granger-cause economic growth. On the other hand, long-run Granger-causality is examined by testing $(H_0): \varphi_k = 0$, using t-statistics, where $k = 1,2,3,4,5$.

4 Empirical results

4.1 Unit root tests

Before conducting the ARDL bounds test, it is crucial to test for variable stationarity to ensure they are either I(0) or I(1). Table 2 presents the findings of our unit root tests. We examined stationarity with both intercept and intercept-and-trend models to verify that none of the variables were integrated to order two. As observed, all variables become stationary at the first order of integration, with some being stationary at level. This confirms the suitability of the ARDL approach for model cointegration.

Table 2: Unit root tests results.

	Augmented Dickey-Fuller (ADF)			
	Intercept		Intercept and trend	
Variables	Level	First difference	Level	First difference
GDP	-1.069	-12.529^{***}	-3.553^{**}	-7.616^{***}
PETRC	-1.466	-7.675^{***}	-3.553^{**}	-7.616^{***}
ELEC	-0.608	-9.940^{***}	-6.004^{***}	-9.854^{***}
ENRMG	-2.785^{*}	-13.960^{***}	-5.653^{***}	-13.844^{***}
CPI	-1.585	-5.770^{***}	-3.205^{*}	-5.983^{***}
	Phillips-Perron (PP)			
	Intercept		Intercept and trend	
Variables	Level	First difference	Level	First difference
GDP	-1.28	-16.574^{***}	-5.402^{***}	-16.437^{***}
PETRC	-1.250	-9.915^{***}	-3.627^{**}	-9.508^{***}
ELEC	-1.208	-21.991^{***}	-6.130^{***}	-21.845^{***}
ENRMG	-4.990^{***}	-18.313^{***}	-5.929^{***}	-18.101^{***}
CPI	-1.543	-6.028^{***}	-2.107	-6.134^{***}
	Kwiatkowski-Phillips-Schmidt-Shin (KPSS)			
	Intercept		Intercept and trend	
Variables	Level	First difference	Level	First difference
GDP	0.993^{***}	0.070	0.104	0.060
PETRC	0.977^{***}	0.133	0.079	0.100
ELEC	1.000^{***}	0.080	0.138^{*}	0.078
ENRMG	0.604^{***}	0.082	0.088	0.077
CPI	1.022^{***}	0.257	0.181^{**}	0.083

Note: ***, ** et * denote statistical significance at 1%, 5% and 10%, respectively. The lag lengths for the ADF and PP tests are automatically chosen by Schwarz's Bayesian information criteria. The bandwidth for the KPSS test is automatically selected through the bandwidth selection procedure proposed by Newey & West (1994). The null hypothesis of the ADF and the PP tests is that the series are not stationary while the null hypothesis of the KPSS test is that the series are stationary.

4.2 ARDL bounds test

The results of the ARDL bounds test are presented in Table 3. It shows that the optimal model determined by the Hannan–Quinn information criterion is ARDL$(1,2,4,3,0)$. The test findings reveal that the computed F-test statistic is 9.587319, which is significant and greater than the upper bound value for 5% and 1% statistical significance as specified by Narayan (2005). Therefore, the Bounds test outcome confirms the existence of a cointegration connection among dependent and independent variables at the 1% significance level.

Table 3: Bounds F-test outcome.

Estimated Model	**Lag order**	**F-statistics**
$F_{GDP}(GDP_t \mid ELEC_t, PETRC_t, ENRMG_t, CPI_t)$	1,2,4,3,0	9.587319***
Critical values for F-statistics	**Lower bound I(0)**	**Upper bound I(1)**
10%	2.323	3.273
5%	2.743	3.792
1%	3.710	4.965

Note: *** denotes statistical significance at 1%. Critical values are taken from Narayan (2005) for a sample size of 60.

4.3 Diagnostic and stability tests

Table 4 shows that the ARDL model in this study has met the requirements of standard assumptions because the probability associated with each diagnostic test is greater than 0.1. The diagnostic tests suggest that the residuals are normally distributed, free from serial correlation, and homoskedastic. These results are based on the Jarque-Bera normality test, the Breusch-Godfrey serial correlation LM test, the Breusch-Pagan-Godfrey heteroskedasticity test, and the ARCH test, respectively. Moreover, the Ramsey RESET test confirms that the ARDL model is well-specified.

Table 4: Diagnostic tests.

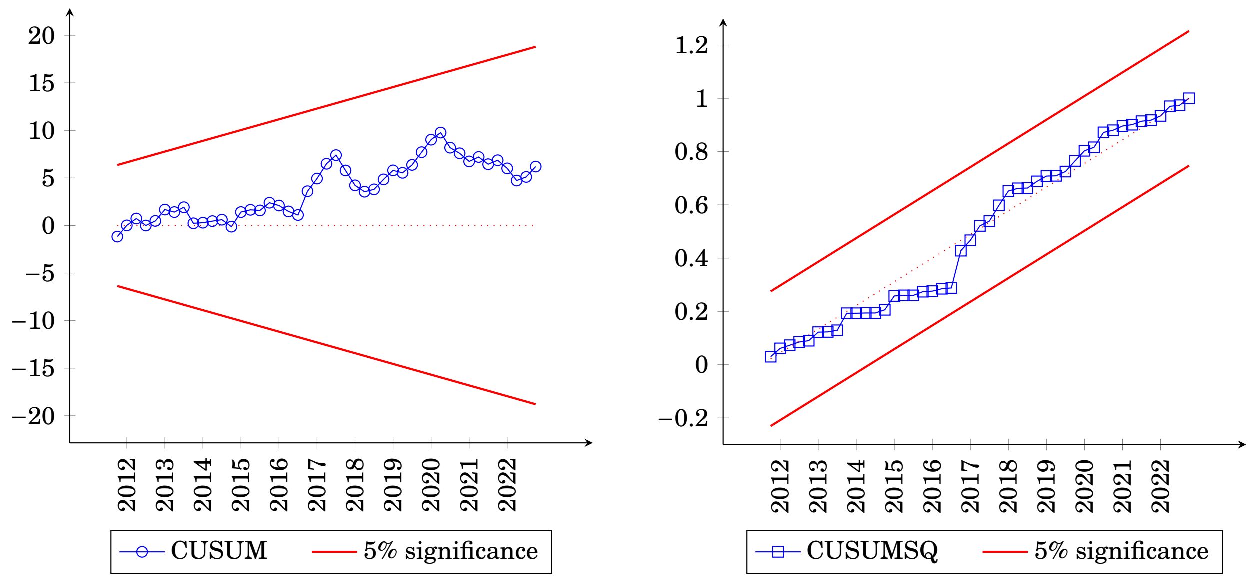
	Normality	**Serial correlation**	**Heteroskedasticity**		**Functional form**
	Jarque-Bera	LM test	Breusch-Pagan-Godfrey	ARCH	Ramsey RESET
χ^2	0.345	0.109	9.296	0.589	1.116
Prob.	0.841	0.947	0.811	0.443	0.297

Besides, Figures 1a and 1b depict the results of CUSUM and CUSUMSQ tests. The plotting of CUSUM and CUSUMSQ statistics are within the critical bounds of 5% significant level, which is the significant value line and determines the stability of the estimated methodology. These results mean that the model is valid and robust, and can be used for policy recommendations.

4.4 Coefficient estimation results

Table 5, Panel A, presents the long-run coefficients of economic growth with respect to the independent variables. Notably, both electricity and petroleum consumption positively influence economic growth. On the one hand, a 1% increase in electricity consumption leads to an increase of 0.352% in GDP. Therefore, recognizing the vital role of electricity access in Madagascar's expanding economy, the government's focus on promoting a diversified electricity generation mix, prioritizing solar and hydropower, holds the potential to significantly accelerate economic growth if rigorously implemented (MEH, 2015; Praene et al., 2017; Rafitoson, 2017). Furthermore, a 1% increase in petroleum

Figure 1: CUSUM and CUSUMSQ plots.



(a) Cumulative sum of recursive residuals.

(b) Cumulative sum of squares of recursive residuals.

consumption results in a 0.363% increase in GDP. Specifically, prioritizing infrastructures that optimize petroleum consumption like efficient road networks, strategically located logistics hubs, and modernized processing facilities in mining and other key industries, could drive substantial economic growth across Madagascar. However, neglecting the counterpoints would be shortsighted. Long-term reliance on fossil fuels exposes Madagascar to price volatility, supply chain vulnerabilities, environmental degradation, and resource depletion, potentially undermining future economic gains.

Moreover, we see that Madagascar's dependence on imported energy weighs heavily on its GDP. Table 5 reveals a statistically significant negative impact of energy imports on the country's long-run economic performance. A 1% increase in energy imports, in fact, reduces GDP by 0.301%. This aligns with Murshed et al. (2020)'s findings for Sri Lanka, which attributed the negative impact to the country's trade balance deficits. Similarly, trade balance deficits have been a persistent challenge for Madagascar's economy throughout its history (Douane Malagasy, 2023; INSTAT, 2022b; INSTAT-MADIO, 1997). Additionally, the observed deficits of trade balance for energy underscore the heavy dependence of its economy on imported energy (Subtil, 2021). To counter this vulnerability and improve economic performance, reducing the demand for imported fuels and diversifying the national energy mix with domestic renewable sources become crucial (Surroop & Raghoo, 2018).

Besides, a 1% increase in global prices significantly reduces Madagascar's GDP growth by 0.143 percentage points, likely due to the country's heavy reliance on energy imports. This sensitivity underscores the trade-off policymakers face: prioritize immediate energy security through continued fossil fuel reliance, or invest in long-term energy diversification towards renewable sources. Balancing energy needs with long-term sustainability considerations will be crucial to ensure Madagascar's economic trajectory remains resilient to volatile energy markets (Ahuja & Tatsutani, 2009).

Table 5 also reports the results of short-run estimates (see Panel B). The results show that the sign of the lagged error-correction term (ECT_{t-1}) is statistically significant at the 1% level with negative sign. The value of the coefficient is −0.975, which suggests that about 97.5% of the last quarter's disequilibrium is corrected in the current quarter. Therefore, any short-run deviation will take about 1.02 quarters to bring the shock back to equilibrium. Regarding the short-run model's goodness of fit, the regression results imply that economic growth is moderately explained by the explanatory variables incorporated in the model. The adjusted R-squared reveals that 66.6% of the short-run

Table 5: ARDL Long- and short-run results.

Panel A. Long-run coefficients		**Panel B. Short-run coefficients (cointegrating form)**	
Variables	Coefficient (std. Error)	Variables	Coefficient (std. Error)
$ELEC_t$	0.352 (0.110)***	$\Delta ELEC_t$	0.080 (0.057)
$PETRC_t$	0.363 (0.104)***	$\Delta ELEC_{t-1}$	−0.177 (0.057)***
$ENRMG_t$	−0.301 (0.117)**	$\Delta PETRC_t$	0.328 (0.065)***
CPI_t	−0.143 (0.074)*	$\Delta PETRC_{t-1}$	−0.131 (0.067)*
$Constant$	5.251 (0.350)***	$\Delta PETRC_{t-2}$	0.122 (0.070)*
		$\Delta PETRC_{t-3}$	0.166 (0.069)**
		$\Delta ENRMG_t$	0.135 (0.072)*
		$\Delta ENRMG_{t-1}$	0.350 (0.095)***
		$\Delta ENRMG_{t-2}$	0.131 (0.076)*
		ECT_{t-1}	−0.975 (0.122)***
		R-squared	0.717
		Adjusted R-squared	0.666
		Durbin-Watson	2.011

Note: ***, ** et * denote statistical significance at 1%, 5% and 10%, respectively.

variation in real gross domestic product is explained by the explanatory variable. The Durbin-Watson value of 2.011 indicates that the short-run model is free from serial correlation.

We note that all short-run coefficients are statistically significant, except for the $\Delta ELEC_t$ coefficient. Electricity consumption at lag (-1) has a significant impact on GDP at the 1% level. The results show that a 1% increase in electricity consumption from the previous quarter leads to a 0.177% decrease in current GDP. This suggests that increased electricity demand in the previous quarter may be a potential indicator of a decreased efficiency in the production process. If businesses and households aren't generating sufficient output or value for the electricity consumed, this inefficiency can hinder economic growth. This inefficiency could be attributed to several factors, including outdated and inadequate electrical infrastructure, distribution loss (Kappen, 2018), and most significantly, fuel supply shortage which is one of the main reasons for the load shedding in Madagascar (Ralitera, 2016, 2023). Load shedding disturbs production processes and disrupts household daily routines. For businesses, this may lead to higher electricity consumption in other part of the day, as they reschedule operations and scramble to catch up on lost production. Households follow a similar pattern, adjusting their routines to compensate for the power cuts. This situation ultimately pushes electricity demand beyond its usual peak periods, leading to higher energy bills for both businesses and households.

Our findings for petroleum consumption also show similarities to those for electricity consumption. Petroleum consumption has a significant impact on GDP. The coefficients on the contemporaneous and lagged variables are positive and statistically significant, except for lag (-1) which is negative. This suggests that sudden spikes in petroleum consumption, potentially driven by the need for electricity generation, have short-term negative impacts on economic growth, mirroring the pattern observed with electricity consumption. Furthermore, Madagascar's transportation sector inefficiencies could partially explain the observed pattern. Outdated and poorly maintained infrastructure, congested roads, and inadequate public transportation contribute to increased fuel consumption (Ralitera, 2016). This, in turn, can disrupt production processes and cause a temporary dip in output.

Additionally, our analysis reveals a statistically significant positive short-run relationship between GDP and energy imports. The results show coefficients with positive signs for the contemporaneous and lagged variables. This indicates that increasing energy imports have a direct and positive impact on economic growth in the short run. This finding suggests that increased energy imports, particularly within the near future, can contribute to GDP growth. Again, policymakers must consider the long-term sustainability of this dependence.

4.5 Granger Causality test

The results of the VECM Granger test are illustrated in Table 6. Considering the short-run effects, electricity consumption, energy imports, and global prices Granger-cause GDP in the short run, as evidenced by their significant coefficients at the 1% and 10% levels in the GDP equation. This suggests that these variables have a direct and immediate impact on economic growth. Petroleum consumption does not Granger-cause GDP in the short run, as its coefficient is insignificant in the GDP equation. However, petroleum consumption Granger-causes electricity consumption at the 5% level, indicating a unidirectional causal relationship where petroleum consumption influences electricity consumption. Global prices Granger-causes energy imports at the 1% level, suggesting that changes in global energy prices directly affect energy import decisions in the short run.

Regarding the long-run results, in the GDP equation, the coefficient on the lagged error correction term is significant with the correct sign at the 1% level, confirming the results from the bounds test for cointegration. This implies long-run Granger causality running from energy demand (including electricity and petroleum consumption and energy imports) and global prices to GDP. This means that these variables have a long-term, interactive influence on economic growth, with adjustments occurring over time to maintain equilibrium.

Table 6: Short- and long-run causality tests.

Dependent	**Short-run**					**Long-run**
variables	ΔGDP_t	$\Delta ELEC_t$	$\Delta PETRC_t$	$\Delta ENRMG_t$	ΔCPI_t	ECT_{t-1}
ΔGDP_t	–	10.910^{***}	1.018	3.558^{*}	3.495^{*}	-0.772^{***}
$\Delta ELEC_t$	0.630	–	3.897^{**}	0.117	0.198	0.457
$\Delta PETRC_t$	1.017	0.130	–	0.051	0.008	0.172
$\Delta ENRMG_t$	0.047	0.109	0.584	–	39.630^{***}	0.035
ΔCPI_t	0.142	0.613	0.001	0.030	–	0.012

Note: ***, ** et * denote statistical significance at 1%, 5% and 10%, respectively.

5 Concluding remarks

We conducted a new assessment of the impact of energy demand on economic growth in Madagascar based on 2007Q1–2022Q4 quarterly data from relevant Malagasy authorities. While research on energy and growth specifically in Madagascar remains limited, our study stands out by utilizing exclusively quarterly data from Malagasy authorities. Not only does this approach contribute to valuable locally-driven insights, but also bypasses potential biases and discrepancies inherent in using external data. Moreover, the higher frequency of data enables robust application of econometric techniques, allowing for a more in-depth analysis of the nuanced patterns and relationships between energy and growth in Madagascar.

In this study, we applied the ARDL bounds testing approach and found evidence of cointegration among the series. Our results indicate that, in the long run, electricity consumption and petroleum consumption exert positive and significant effects on economic growth, while energy imports and global prices exhibit negative and significant effects. Next, we employed Granger-causality test based on Error Correction Models to examine the causal relationships between energy demand, global prices, and economic growth. The results revealed the existence of a long-run causality running from both energy demand and global prices to economic growth. Additionally, in the short run, electricity consumption, energy imports, and global prices Granger-cause economic growth; petroleum consumption Granger-causes electricity consumption; and global prices Granger-cause energy imports.

Our findings confirm that Madagascar is an energy-dependent economy and underscores the crucial role of reliable and affordable electricity in powering economic growth. Increasing access to clean electricity can unlock this potential and foster productivity across sectors. However, Madagascar's dependence on volatile external resources like imported petroleum exposes the country to economic vulnerabilities and hinders sustainable development. Diversifying the energy mix with renewables presents a solution, lessening reliance on imported fuels and mitigating risks associated with price fluctuations and supply disruptions. Fortunately, Madagascar boasts significant potential for renewable energy generation, particularly solar, wind, and hydropower. Utilizing these resources offers a cost-effective, secure, and environmentally friendly alternative to fossil fuels, paving the way for economic growth, energy security, and a sustainable future.

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