Economics of Modular Refineries and Energy Security in Nigeria

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Abstract
This research examines the economics of modular refineries and their implications for energy security in Nigeria using annual time-series observations for 2000–2025. It assesses changes in import dependency. The explanatory variables were, import substitution, domestic refining capacity, foreign exchange savings and employment creation. The Augmented Dickey-Fuller tests indicated that the variables were stationary in levels, I(0). On that basis, the study estimated the relationships with an OLS multiple-regression framework and applied Newey-West robust standard errors to address serial-correlation and heteroskedasticity concerns. The results indicate a very high explanatory fit for the model. The analysis recorded an R^2 of 0.993 and an F-statistic of 767.96, with domestic refining capacity, foreign-exchange savings and employment value-addition associated with lower import dependency. The findings further revealed that Import Substitution, Foreign Exchange Saving, Employment value added and Domestic Refining Capacity significantly impact import dependency given their probability values. The study therefore, recommends the expansion of private refining facilities as an important development within Nigeria's downstream sector, while emphasizing the need for clear and transparent institutional arrangements under the Petroleum Industry Act.

Key words: *Modular Refinery, Energy Security, Import Dependency, Import Substitution, Domestic Refining Capacity, Foreign Exchange Savings*

1. Introduction

Nigeria's petroleum sector exhibits a persistent imbalance between crude oil production and domestic refining capacity. Despite being one of Africa's major crude oil producers, the country has historically depended on imported refined petroleum products to meet domestic demand. This situation has been associated with the underperformance of state-owned refineries, inadequate maintenance, operational inefficiencies, and limited capacity utilisation. Consequently, petroleum-product imports have contributed to foreign exchange pressures, supply disruptions, and reduced domestic value addition (Central Bank of Nigeria [CBN], 2022). Dependence on imported petroleum products exposes Nigeria to international price fluctuations and exchange-rate depreciation, which can increase domestic fuel prices, transportation costs, and production expenses. It also creates energy-security concerns by exposing domestic supply to international market disruptions and logistical constraints. Yergin (2006) conceptualises energy security in terms of reliable access to energy at reasonable prices, while Cherp and Jewell (2014) emphasise vulnerabilities arising from threats to essential

energy systems. Improving domestic refining capacity could therefore help strengthen supply reliability and reduce exposure to external market risks.

Limited domestic refining also constrains the economic value Nigeria derives from its crude oil resources. Refining activities can generate employment, promote technical skills development, stimulate industrial linkages, and increase the value retained within the domestic economy. However, these benefits depend on operational efficiency, production costs, access to crude oil, and market demand. Domestic refining capacity must therefore be evaluated not only by installed capacity but also by actual output and its contribution to reducing imports.

Modular refineries have emerged as a potential strategy for addressing these challenges. These relatively small-scale facilities may offer flexibility in deployment, staged investment, and proximity to crude oil sources and regional markets. In Nigeria, facilities such as the Aradel (formerly Ogbele), Waltersmith, and Edo refineries illustrate the development of modular refining capacity. The Petroleum Industry Act (PIA) 2021 provides a broader legal and regulatory framework for petroleum-sector activities, including downstream operations (Federal Republic of Nigeria, 2021). Nevertheless, the contribution of modular refineries depends on feedstock availability, operational reliability, financing, infrastructure, and regulatory compliance.

Furthermore, increased domestic refining does not necessarily translate into equivalent reductions in petroleum-product imports. Modular refineries may contribute more substantially to the supply of diesel, kerosene, or other products than to petrol, depending on their configurations and product yields. Their economic contribution must therefore be assessed in terms of actual production, product-specific import substitution, foreign exchange implications, and domestic value addition.

Despite their potential, the extent to which modular refineries can address Nigeria's downstream petroleum-sector challenges requires further empirical assessment. This study therefore examines their contribution to domestic petroleum-product supply, import dependence, and energy security, considering their potential to improve refining performance and strengthen the domestic petroleum value chain.

2. Literature Review

Import Substitution Industrialization (ISI) Theory

Import Substitution Industrialization (ISI) theory originated in the 50s from the works of Raul Prebisch (1950) and Hans Singer. It is a Latin American structuralist theory that proposes a developmental strategy for industrializing countries and improving their balance of payments. The authors emphasized the need for developing countries to replace the import of finished products with their own production to attain economic independence and improve their balance of payments. ISI is based on several key principles. The first one is the infant Industry Argument that postulates that emerging industries like the modular refining industry in Nigeria need to be protected from the strong foreign competition for them to develop. The protectionism measures could be in the form of subsidies, tax holidays, or favorable feedstock agreements. The next principle is Foreign Exchange (Forex) Conservation. The ISI theory states that by substituting imports, a country can help conserve its Forex. In Nigeria, it means reducing the pressure on the Naira and saving its foreign exchange reserves. The Naira has been constantly vulnerable to depreciation against the USD due to the huge amount of funds required to import PMS. According to the Central Bank of Nigeria, oil products have constituted the bulk of Nigeria’s total imports in the past. Besides, the ISI theory also postulates the Backward and forward linkages. The argument suggests that the developmental process in one industry will create a forward and backward linkage, which creates new demand in related industries and facilities. The backward linkages in the case of modular refinery mean that the

refining industry will create more demand for the domestic crude oil. The forward linkages are that it will provide energy at a lower cost to the manufacturing and transportation sector.
The application of ISI theory in Nigeria's petroleum sector is an eye-opener. Instead of allowing PMS to be imported and crude oil exported, Nigeria can generate profits from its refining industry. Therefore, the modular refining projects should be a welcome measure to help diversify the Nigerian economy and provide energy security through domestic refining.
Modular refineries are perfect for the application of ISI theory in Nigeria. They are capitalizing on the strategy of localization to help reduce the Nigerian economy's exposure to global petrol price volatility. Using the Nigerian refining industry as a case study, this thesis will reveal how modular refinery projects can be applied to enhance Nigeria's energy security by substituting petrochemical imports.

Energy Security Theory

Energy Security Theory conceptualizes energy security as the ability to ensure reliable and affordable energy supplies while minimizing vulnerability to external disruptions. Initially shaped by the oil crises of the 1970s, the concept has evolved to encompass short-term supply reliability, long-term adequacy, and system resilience (IEA, 2022). Cherp and Jewell (2014) identify four dimensions of energy security: availability, accessibility, affordability, and acceptability, which provide a framework for analysing Nigeria's downstream petroleum sector. Availability refers to the adequacy of energy resources to meet domestic demand. Despite Nigeria's substantial crude oil resources, inadequate domestic refining capacity has contributed to dependence on imported petroleum products. Modular refineries could help address this imbalance by increasing local production. Accessibility concerns the physical delivery of energy to consumers. Pipeline disruptions and distribution constraints can impede petroleum-product supply, while modular refineries located near crude oil sources and regional markets may shorten supply chains and improve distribution reliability.
Affordability refers to the ability of households and industries to obtain energy at reasonable prices. In Nigeria, petroleum-product prices are influenced by exchange-rate movements, international oil prices, and import dependence. Increased domestic refining could reduce exposure to import-related costs, although the extent of any price reduction would depend on production efficiency and market conditions. Acceptability concerns the environmental and social compatibility of energy production. Informal refining activities have been associated with environmental degradation, whereas properly regulated modular refineries may support safer production practices and formal employment, provided that appropriate environmental standards are enforced. Yergin (2006) argues that energy security extends beyond preventing supply interruptions to include diversification, investment, and resilience. This perspective is particularly relevant to Nigeria, where refining constraints and dependence on imported petroleum products contribute to energy insecurity despite abundant crude oil resources. Accordingly, this study applies Energy Security Theory to examine whether modular refineries can improve domestic petroleum-product availability, strengthen supply reliability, reduce import dependence, and support affordable and environmentally responsible energy provision. The theory thus provides a framework for assessing the potential contribution of modular refineries to Nigeria's energy security and macroeconomic resilience.

Resource Curse Theory

Resource Curse Theory, otherwise termed 'Paradox of Plenty', explains how nations blessed with plenty of resources do not necessarily translate them into widespread development. Literature attributes the issue to weak institutions, lack of diversification, economic instability and governance challenges. Research studies cited in this thesis examine the phenomena in

various aspects. For instance, Sachs and Warner (2001) and Okpebenyo et al. (2023) discuss the underlying mechanisms in resource-rich economies. However, in the Nigerian context, factors such as oil abundance and its attendant challenges in the oil-producing communities have been examined (Akpotor, 2016). Others looked at historical institutional and commercial structures of petroleum in the Niger Delta (Tumbo, 2011).

The following three mechanisms are particularly pertinent to the Nigerian context in explaining why the country has not been able to harness its vast crude oil resources for development. They include the Dutch Disease whereby natural resource exports are said to adversely impact the development of other non-resource sectors through depreciation in the exchange rate of the importing country. Secondly, Rent-seeking activities emanate from natural resource wealth where the rents are not sufficient to motivate accountability in governance and new investments. The third one is the oil-producer/importer paradox which states that even though a nation may have plenty of crude oil, it could still face shortages of its refined products. Karl (1997) talks about the 'Paradox of Plenty'. Similarly, Okpebenyo et al. (2023) examine the issue of institutional weaknesses, lack of transparency, and difficulties in utilizing extractive industries' revenues.

Nigeria is a case in point of the paradox of plenty because even though it is one of the largest producers of crude oil in Africa, it has to import its refined petroleum products. In other words, the country has been unable to fully utilize its comparative advantage in crude oil production to generate benefits accruing from the production of its refined products. The reason is that it lacks adequate downstream refining capacity to refine the crude oil it produces for use in its industries. Modular refineries can be a partial solution to the problems of the Nigerian refining industry which have persisted over time. They would help to add value to the crude oil production and reduce the cycle of exporting crude oil and importing refined petroleum products. Thus, Resource Curse Theory helps explain why Nigeria has not been able to fully utilize its vast crude oil reserves for downstream refining and why the proposed modular refineries would be of benefit to Nigeria. By examining the theories related to the Resource Curse phenomenon, it becomes possible to identify the factors that must be considered as Nigeria seeks to develop its refining capacity for its economic survival.

Empirical Review

Adekola (2023) identifies the "Forex Trap." He argues that the Nigerian National Petroleum Company (NNPC) and private marketers are the largest "demanders" of Dollars in the country. He found a 92% correlation between the volume of fuel imports and the widening gap between the official and parallel market exchange rates. To him modular refineries aren't just "fuel plants"—they are monetary tools that reduce the central demand for USD.

Adekola (2023) explored the macroeconomic implications of local refining on Nigeria's currency stability. Utilizing a Vector Error Correction Model (VECM) approach on data spanning 2010–2022, the author established that the continuous outflow of foreign exchange for fuel imports acts as a primary driver of Naira volatility. Adekola's findings revealed that increasing domestic refining capacity by even a small margin creates a 'Forex Shield' by eliminating dollar-denominated landing costs.

The study by Emele and Okorie (2025) moved the discussion from simple accounting to monetary policy. In their study, they examined the intersection of monetary policy and energy security with focus on the micro-foundations of forex scarcity.They treat modular refineries not just as industrial plants, but as tools for Liquidity Management.

Ogbunweze (2024) compares private modular-refinery operations in the Niger Delta and argues that local processing can reduce some foreign-exchange costs associated with importing finished fuels. The analysis emphasizes that imported products carry additional maritime and

port-related expenses, including vessel chartering, insurance, ship-to-ship transfers and port charges. Because modular plants can process crude closer to producing areas, some of these external logistics costs may be avoided, creating potential savings for the domestic economy.

Iheanacho (2024) investigated the "Pass-Through Effect" of exchange rate volatility on domestic fuel prices. He concluded that because imported fuel is priced in USD, Nigerian consumers are at the mercy of Naira devaluation. His empirical evidence suggests that modular refineries, by pricing in Naira (or local cost structures), can provide a 15%–20% price buffer compared to imported products. A unique insight from Iheanacho is that modular refineries aren't just for making fuel; they are monetary tools. His Argument is -by refining locally, Nigeria converts a "USD-denominated expense" (importing fuel) into a "Naira-denominated activity" (local refining). This reduces the demand for Dollars, which in turn helps stabilize the Naira. He calls this "Sectoral De-dollarization." Iheanacho notes that relying on international shipping for 90% of national fuel needs is a massive national security risk. Any global event—such as a war in Europe, a strike at a foreign port, or a surge in international freight costs—causes immediate fuel queues and "scarcity" in Nigeria.

Koozakar (2026) reports that there has been a very low utilization of the major state refineries during the period 2015 - 2024 and attributes this to technical deterioration and inadequate turnaround maintenance. Modular facilities have sprung up partly to address this shortfall. NMDPRA (2026) indicates that operating modular plants have achieved a higher utilization than the aging state facilities, although their performance is impacted by feedstock and other operational constraints.

Ogundari et al (2025) conducted a sustainability audit of the Waltersmith plant in Ibigwe. Their findings showed that they maintained a stable capacity utilization of 61% - 63% between 2024 and 2025. This was attributed to its co-location to an upstream crude source (the Ibigwe field) which reduced feedstock supply interruptions.

Onah (2024) examines the gap between Installed Capacity (what the refinery is built to produce) and Effective Capacity (what it actually produces). His work is vital because he provides the 'Institutional Context'. He found that in the Nigerian environment, DRC often degrades at a rate of 5-8% annually without a specialized, consistent maintenance schedule and consistent access to technical parts causing a 'Maintenance Gap'. Onah defines the Maintenance Gap as the discrepancy between a refinery's "Nameplate Capacity" and its "Sustainable Throughput." In his findings, he observed that while modular refineries are advertised as "low maintenance" compared to conventional plants, they are very sensitive to catalyst exhaustion and corrosion. Onah argues that the maintenance gap is widened by the lack of local high-end technical skills. Most modular plants in Nigeria (like Waltersmith or Aradel) utilize technology from the US, China or Europe. When a specialized component fails, the refinery must wait for expatriate engineers to fly in. This causes 'Foreign Expert' Dependency.

3. Methodology

This study adopted an Ex-Post Facto research design, which is a systematic empirical inquiry where the researcher does not have direct control of independent variables because their manifestations have already occurred. The data for this study was sourced from the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA), and the National Bureau of Statistics (NBS), and from 2000 to 2025. The modelling of this study was theoretically anchored on the Classical Trade Theory.

The study specifies the following models:

$$ID = f(IS\ \ DRC\ \ FES\ \ ELVA) \quad 3.1$$

$$ID_t = \beta_0 + \beta_1 IS_t + \beta_2 DRC_t + \beta_3 FES_t + \beta_4 ELVA_t + \mu_{1t} \quad 3.2$$

Where:
ID = Import dependency
IS = Import substitution
DRC = Domestic refining capacity
FES = Foreign exchange savings
ELVA = Employment and local value addition
μ_{1t} = error term

4. Data Analysis

Table 4.1: Summary of Augmented Dickey-Fuller (ADF) Unit Root Test Results

Variable	ADF Stat (Level)	5% Critical Value	Order of Integration
ID	0.0002	-3.644	I(0)
FES	0.0021	-3.012	I(0)
IS	0.0076	-3.644	I(0)
DRC	0.0000	-3.012	I(0)
ELVA	0.0038	-3.644	I(0)

The Augmented Dickey-Fuller (ADF) test was employed to establish the order of integration for the dataset. The decision rule is to reject the null hypothesis of a unit root (non-stationarity) if the ADF test statistic is strictly more negative than the critical value. All the variables were integrated at levels after carrying out the ADF Unit root test in Eviews, using max lag 4. Table 4.1 presents the ADF test results evaluated at the level.

Model Estimation

Dependent Variable: Import Dependency (ID)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
IS	0.226271	0.020435	11.07289	0.0000
FES	-0.233656	0.021976	-10.63228	0.0000
ELVA	-0.005350	8.45E-05	-63.33675	0.0000
DRC	-0.000752	8.86E-05	-8.494605	0.0000
C	446.5585	39.12084	11.41485	0.0000

R-squared	0.993210	Mean dependent var	70.82308
Adjusted R-squared	0.991917	S.D. dependent var	18.46431
S.E. of regression	1.660065	Akaike info criterion	4.022632
Sum squared resid	57.87211	Schwarz criterion	4.264573
Log likelihood	-47.29421	Hannan-Quinn criter.	4.092302
F-statistic	767.9575	Durbin-Watson stat	2.537274
Prob(F-statistic)	0.000000	Wald F-statistic	9395.789
Prob(Wald F-statistic)	0.000000		

Source: *Researcher's E-view Based Results, 2026*

The R-squared value of 0.993 indicates that approximately 99.3% of the total variation in import dependency is jointly explained by domestic refining capacity, employment value added, forex savings, and import substitution. The adjusted R-squared (0.991) further confirms a strong, robust overall goodness of fit after accounting for degrees of freedom. Having F-statistic value at 767.96 with a p-value of 0.0000 demonstrates that the overall regression model

is globally statistically significant at the 1% level. The coefficient values of IS, FES, ELVA and DRC are 0.22627, -0.233656, -0.005350 and -0.000752 respectively. With all having a p-value of 0.0000. Because their p-values are less than 0.01, they are all statistically significant at the 1% level. FES value indicates that higher foreign exchange savings effectively lower national import dependency. The value of ELVA shows that enhanced industrial employment generation reduces reliance on imported goods, highlighting the positive role of job creation and labor productivity in industrial capacity performance. DRC p- value confirms that expanding local refining capacity significantly reduces import dependency.

The T-test was carried out to check the validity of the parameter estimate. It was used to decide whether each of the independent variable has a meaningful, statistically significant effect on Import Dependency or not. In carrying out this test, the researcher made use of n-k-1 degrees of freedom and 5% level of significance.

Where n: Sample size.

K: Number of parameters.

Degree of freedom (df): Calculated as n-k-1

In this study, n = 26 while k = 4. Thus, n-k-1 = 26 - 4-1 = 21.

If the T-calculated value is greater than the T-tabulated value, reject at 5% level of significance, the null hypothesis (H_0) which states that individual parameter in the specified model is not statistically significant. On the other hand, if T-calculated value is less than the T-tabulated value, accept at 5% level of significance, the null hypothesis (H_0) which states that individual parameter in the specified model is not statistically significant.

From statistical table, T-tabulated value at 21 degrees of freedom and at 5% level of significance is 2.079614. Below is the T-calculated values, T-tabulated values, decision rule and conclusion for all the independents variables.

Table 4.2: Summary of T-Test for the model

Variables	T-Calculated Value	T-Tabulated Value	Decision Rule	Conclusion
IS	11.07289	2.079614	Reject H_0	Significant
FES	-10.63228	2.079614	Reject H_0	Significant
ELVA	-63.33675	2.079614	Reject H_0	Significant
DRC	11.41485	2.079614	Reject H_0	Significant

Source: *Researcher's E-view Based Results, 2026*

Examining the table 4.2 above, all the independent variables have their T-Calculated value higher than the T- Tabulated value (2.079614), ignoring the negative signs of FES and ELVA, making them significant at the 5% level. Meaning they have a meaningful impact on the dependent variable, Import dependency.

This F- test was carried out to test for overall significance of the model. It checks whether all the independent variables are working together to create a valid and reliable model. In carrying out this test, the researcher made use of the values of k and n-k-1 degrees of freedom and 5% level of significance.

Where;

n: Sample size.

K: Number of independent variables.

In this study, n = 26 while k = 4.

Thus, n-k= 26-4-1=21

If the F-calculated value is greater than the F-tabulated value, reject at 5% level of significant, the null hypothesis (H_0) which states that overall parameter estimated is not statistically

significant. But if F-calculated value is less than the F-tabulated value, accept at 5% level of significant, the null hypothesis (H_0) which states that overall parameter estimated is not statistically significant.

Table 4.3: Summary of F-test for the model

Variable	F-calculated Value	F-tabulated Value	Decision Rule	Conclusion
Estimated Model	767.957	2.840	Reject H_0	Significant

Source: *Researcher's E-view Based Results,2026*

The summary of the F-test as presented in table 4.3 above shows that the estimated model is statistically significant and reliable, since the F- calculated value (767.957) is higher than the F- tabulated value (2.840). This simply proves that the group of independent variables jointly influence Import dependency in Nigeria.

Table 4.4: Post- estimation test results for the model

Test Type	Test Statistic	Prob. Value	Inference
Jarque-Bera Normality Test	136.624	0	Not normally distributed
Breusch-Godfrey Serial Correlation LM Test	43.061	0	Serial correlation present
Breusch-Pagan-Godfrey Heteroskedasticity Test	7.5858	0.0006	Heteroskedasticity present
Ramsey RESET	1.285	0.289	Correctly specified

Source: E-views software output (2026)

The diagnostic results show a Jarque-Bera statistic of 136.624 with a probability value of 0.0000; the normality null hypothesis is therefore rejected. The Breusch-Godfrey test also produced a probability value of 0.0000, indicating serial correlation in the residuals. The study addressed this issue by using Newey-West robust standard errors in the OLS estimation. The Breusch-Pagan-Godfrey test returned a probability value of 0.0006, providing evidence of heteroskedasticity. Finally, the Ramsey RESET statistic was 1.285 with a probability value of 0.289, so the null hypothesis of correct functional specification was not rejected.

5. Conclusion and Recommendations

Conclusion

This study concludes that the historical era of absolute petroleum import dependency in Nigeria has been structurally transformed by the emergence of private modular refineries and downstream market reforms. Grounded in Import Substitution Industrialization (ISI) Theory, Energy Security Theory and Structural Change Theory, the empirical evidence confirms that modular refineries function as powerful macroeconomic catalysts rather than isolated processing units. By scaling domestic refining capacity, modular refineries successfully curb heavy reliance on imported petroleum products, conserve vital foreign exchange reserves, produce robust employment and supply the reliable energy inputs that elevate industrial capacity utilization across the Nigerian economy. Furthermore, the findings emphasize that

physical refining infrastructure should be supported by transparent institutional frameworks such as the Petroleum Industry Act (PIA) to ensure long term investor confidence and macroeconomic stability.

Recommendations

Based on the findings and conclusion drawn from this study, the following recommendations are made:

i. The Federal Government and Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) must streamline licensing procedures, environmental approvals and tax holidays for modular refinery operators to attract sustained private capital.

ii. Nigerian authorities must strictly enforce localized crude invoicing and mandatory crude feedstock allocations to modular refiners (in line with the Petroleum Industry Act). This will insulate local plants against international price shocks and foreign exchange volatility.

iii. Industrial policies should encourage modular refinery operators to integrate secondary processing and petrochemical value chains, transforming the petroleum sector from being a raw extraction enclave into a diversified industrial driver that maximizes Employment Value-Added (ELVA).

iv. Monetary authorities should prioritize foreign exchange access for the procurement of critical machinery components while fiscal agencies introduce targeted credit facilities to support indigenous entrepreneurs investing in decentralized refining technology.

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