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Assessing the Impact of the Electricity Mix on Economic Growth in Morocco: An ARDL Approach

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Abstract. This article examines the impact of the electricity mix on economic growth in Morocco between 1990 and 2023. The application of an autoregressive distributed lag (ARDL) model shows a stable long-term relationship between fossil fuels and renewable energy used in electricity generation and GDP. In the long-run, fossil fuels have a sustained positive effect of 0.334, while renewable energy sources have an impact of 0.070, indicating that investments in clean energy lead to steady economic benefits over time. In the short-term, both electricity sources show positive effects with, coefficients of 0.206 for fossil fuels and 0.066 for renewable energy. However, these effects vary depending on the lags, reflecting the fact that electricity production in Morocco remains dependent on fossil fuels with an immediate opening to renewable energy. Gross fixed capital formation (GFCF) likewise emerges as a significant driver of economic performance, with elasticities of 0.470 in the long-run and 0.278 in the short-run, due to investments in infrastructure and production capacity. The error correction term (ECM= -0.621), reveals that 62% short-term imbalances are corrected annually, confirming the ability of Morocco to restore long-run equilibrium. The model has a high explanatory power ($R^2 = 0.998$; adjusted $R^2 = 0.996$). These results highlight the need to accelerate the deployment of renewable energy and consolidate energy policies in line with SDGs 7 and 8.

Introduction

Energy has become a central issue in contemporary economic and environmental debates, especially in countries that are developing, where electricity demand is growing consistently due to population growth and industrialization [1]. In Morocco, the issue of electrical energy is considered as a key driver of economic and energy security, given the country's continued reliance on imported fossil fuels [2]. Even though the country's progress in renewable energy, fossil fuels are still the dominant energy source [3]. This persistent dependence underscores the need for thorough evaluation of the economic consequences associated with prevailing energy mix, given that the composition of electricity generation directly affects long-term growth prospects, competitiveness, and the sustainability of the development model [4].

The literature has long recognized the strategic role of energy in fostering economic growth. While Solow's neoclassical model [5] emphasizes capital and labor, more recent research identifies energy as a vital input that significantly enhances productivity and economic development [4]. Moreover, the pace of economic activity, industrial competitiveness, and overall macroeconomic stability are strongly affected by the composition, efficiency, and availability of the energy mix [6].

At the same time, a key challenge of the 21st century is energy transition. It entails the gradual alteration of energy production and consumption toward a low-carbon model, with the aim of achieving energy security, economic competitiveness, and environmental sustainability [7]. Since the adoption of the Paris Agreement, countries have committed to limit global warming to 1.5°C, implying a significant reduction in the fossil fuels use and a rise in the utilization of renewable

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sources [8]. In this context, Geels [9] argues that transition involves not only technological change, but also a significant reconfiguration of the economic, institutional, and social structures.

In this sense, Morocco is manufacturing bold efforts to vary its energy mix, with its various investments such as Noor solar complex of Ouarzazate and wind farms of Tarfaya and Tangier. Via these investments, in 2021, renewable sources accounted for 37.2% of installed capacity [10], with an ambition to rise their share to 52% in electricity production by 2030 [11]. Nevertheless, Morocco still faces challenges such as the intermittency of renewable energy, the high cost of infrastructure, and the continued strong dependence on coal in the national electricity mix [12].

This situation reveals a central question regarding the effect of Morocco's energy diversification on economic performance. When a country moves around a low-carbon model, it has been crucial to evaluate how the composition of the electricity mix combining fossil fuels and renewable energy shapes the dynamic of economic growth. In this case, the objective is to examine through an empirical modeling approach the extent to which energy choices influence this dynamic, taking economic into account both short-term fluctuations and long-run trends. This analysis considers not only the economic dimension but also the perspective of sustainable development. Indeed, Sustainable Development Goal (SDG) 7 emphasizes the need to secure universal access to reliable, sustainable, and modern energy, while SDG 8 calls for inclusive and sustained economic growth based on the efficient and responsible use of energy [13].

Research Methodology

Data sources and variables studied. The data employed in the present study come from reliable sources such as the World Bank [14], World Perspective [15] and World Energy Balances [16].

The study is based on an annual database of the Moroccan economy between 1990 and 2023, which covers all the necessary variables relating to the energy mix in electricity production and economic growth (Table 1). The dependent variable is real GDP, which reflects Morocco's economic performance. The explanatory variables include energy-related variables, such as proportion of electricity production from fossil fuels (FOSS) and renewable energy (REN), which enable changes in Morocco's electricity mix to be measured. The model also includes essential variables, namely gross fixed capital formation (GFCF), representing investment and labor (LF) measuring the working population and the value added by the industrial sector (IND). The integration of GFCF and labor represents the two essential key factors of the Cobb-Douglas production function: capital and labor. We applied the logarithm to standardize the variables.
The analysis was conducted using Eviews software (version 10).

Table 1. *Overview of variables used*

Variables	Description	Source
GDP	Gross Domestic Product	World Perspective
FOSS	Share of fossil fuels in electricity generation	World Energy Balances
REN	Share of renewable energy in electricity generation	World Energy Balances
GFCF	Gross fixed capital formation	World Bank
LF	Labor force	World Bank
IND	Added value of the industrial sector	World Bank

Methodological approach. This study's methodological approach, which is based on quantitative analysis, relies on the Autoregressive Distributed Lag (ARDL) model developed by Pesaran and Shin [17] and Pesaran et al. [18]. This approach allows us to test for short and long-term relationship between variables with different integration orders (I(0) or I(1)). It provides a flexible analytical framework for assessing the impact of the energy mix in electricity production on economic growth in Morocco from 1990 to 2023, accounting for adjustment dynamics over time.

ARDL model specification. The empirical analysis is based on the following ARDL model specification:

$$lGDP_t = a_0 + a_1 lFOSS_t + a_2 lREN_t + a_3 lLF_t + a_4 lGFCF_t + a_5 lIND_t + \varepsilon_t$$

To capture the short and long-term dynamics between economic growth and explanatory variables, the general form of the ARDL model is written as follows:

$$\Delta lGDP_t = a_0 + \sum_{i=1}^{p} a_{1i}\Delta lGDP_{t-i} + \sum_{i=0}^{q} a_{2i}\Delta lFOSS_{t-i} + \sum_{i=0}^{q} a_{3i}\Delta lREN_{t-i} + \sum_{i=0}^{q} a_{4i}\Delta lLF_{t-i} + \sum_{i=0}^{q} a_{5i}\Delta lGFCF_{t-i} + \sum_{i=0}^{q} a_{6i}\Delta lIND_{t-i} + b_1 lFOSS_{t-i} + b_2 lREN_{t-i} + b_3 lLF_{t-i} + b_4 lGFCF_{t-i} + b_5 lIND_{t-i} + \varepsilon_t$$

Where $\boldsymbol{a_0}$ corresponds to a constant term; Δ is the first difference operator; $\boldsymbol{a_1}$,…,$\boldsymbol{a_6}$ represent short-term effects; $\boldsymbol{b_1}$…$\boldsymbol{b_5}$ concern the long-term dynamics of the model; $\boldsymbol{\varepsilon_t}$ is the error term and t corresponds to the time horizon.

RESULTS AND DISCUSSION

Empirical results. The empirical assessment of the impact of the energy mix in electricity production on economic growth in Morocco was carried out using the ARDL (1.2.2.0.2.0) model. The Akaîke Information Criterion (AIC) was used to select the model presented in Figure 1, which ensures the best possible specification for capturing short and long-term dynamics [18].

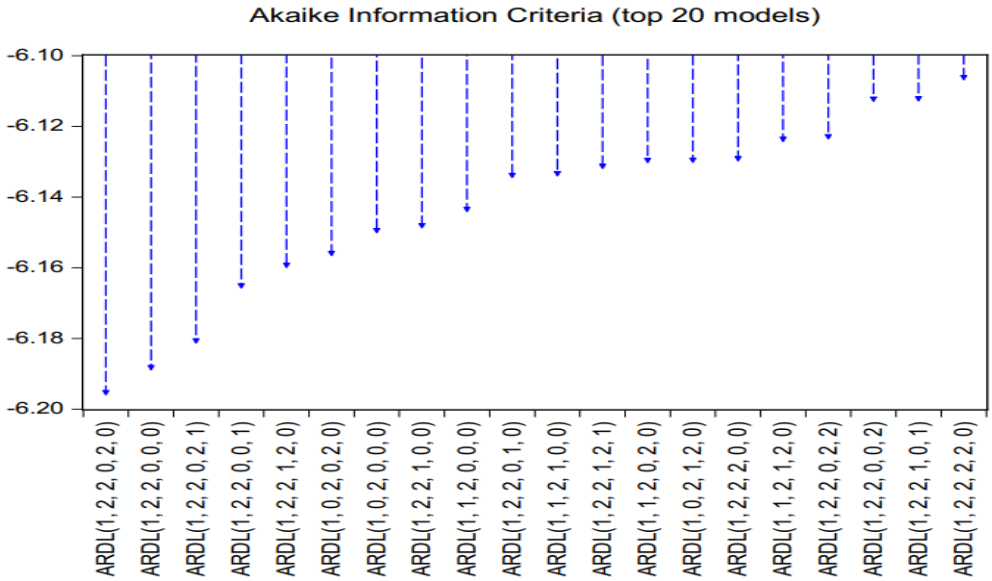


Fig. 1 *The optimal ARDL model*

Before estimating the selected ARDL model, it is necessary to examine the stationarity of the series in order to determine their integration orders and ensure the validity of the estimates.

Stationarity test. The Table 2 below presents the results of the Augmented Dickey-Fuller (ADF) stationarity tests for the various variables studied.

Table 2. *Results of Dickey and Fuller augmented tests (ADF)*

Variables	Level	1st difference	Integration order
lGDP	-0.6975 (0.8334)	-10.5834 (0.0000)***	I(1)
lFOSS	-0.7810 (0.8114)	-7.2877 (0.0000)***	I(1)
lREN	-0.9278 (0.7666)	-5.1392 (0.0002)***	I(1)
lLF	-1.4028	-4.5615	I(1)

	(0.5690)	**(0.0010)*** **	
lGFCF	**0.0732**	**-4.7879**	**I(1)**
	(0.9581)	**(0.0006)*** **	
lIND	**-3.1543**	**-5.8576**	**I(0)**
	(0.0321) **	**(0.0000)*** **	

****** Significant at 1%. **Significant at 5%.*Significant at 10%.***

In this regard, our variables display different integration orders I(0) and I(1), which justifies the use of the ARDL model.

Estimation of the ARDL model. After determining the integration order, the analysis proceeds with the estimation of the ARDL model (1.2.2.0.2.0). The results are shown in Table 3, which illustrates the impact of the electricity mix on economic growth in Morocco.

Table 3. *ARDL model estimation (1.2.2.0.2.0)*

Variables	Coefficient	Erreur Std.	t-stat	p-value
lGDP(-1)	0.378653	0.186083	2.034863	0.0561*
lFOSS	0.206147	0.084300	2.445391	0.0244**
lFOSS (-1)	-0.139612	0.095180	-1.466825	0.1588
lFOSS (-2)	0.139385	0.086457	1.612195	0.1234
lREN	0.066025	0.014930	4.422413	0.0003***
lREN (-1)	-0.067960	0.018665	-3.641124	0.0017***
lREN (-2)	0.045147	0.012317	3.665529	0.0016***
lLF	-0.003892	0.003788	-1.027252	0.3172
lGFCF	0.277615	0.090830	3.056430	0.0065***
lGFCF (-1)	-0.160623	0.130361	-1.232135	0.2329
lGFCF (-2)	0.144149	0.091026	1.583592	0.1298
lIND	-0.001840	0.001854	-0.992342	0.3335
Intercept	3.198352	0.951296	3.362101	0.0033***
R-Squard		0.997802		
Adjusted R-squared		0.996413		
F-statistic		718.6207		
Prob(F-statistic)		0.000000		

****** Significant at 1%. **Significant at 5%.*Significant at 10%.***

The ARDL estimation (Table 3) indicates that the one period lagged GDP variable, carries a positive coefficient of 0.3786, significant at the 10% level with a probability of 0.0561. Regarding the energy mix, the share of fossil fuels (lFOSS) in electricity generation exerts a positive and statistically significant impact at the 5%, with a coefficient of 0.206 and a probability of 0.024. This result implies that a 1% increase in the use of fossil fuels contributes 0.206% to economic growth. In contrast, the coefficients of the first lag and the second lag are not significant, suggesting the effect is confined to the short-term and does not persist over the time. Conversely, the share of renewable energy (lREN) has a positive effect that is highly significant effect at the 1% threshold, with a coefficient of 0.066 and a probability of 0.0003. These two successive (lREN) lags are also significant at the 1% threshold, reflecting a dynamic in which the economic gains from renewables appear immediately, but are followed by a negative adjustment.

The variable (lGFCF) has a positive coefficient of 0.277 and a probability of 0.0065, which is significant at the 1% threshold. However, its lags are not significant. Conversely, the labor force (lLF) and the value added by the industrial sector (lIND) show no significant effect, suggesting that they do not immediately contribute to GDP dynamics within the estimated model framework. Finally, the Moroccan model has exceptional explanatory power, with an R^2 of 0.9978 and an adjusted R^2 of 0.996. This means that the variables considered explain almost all of the variation in GDP. Fisher's overall test is highly significant (F-statistic = 718.6207; p = 0.0000), confirming the model's robustness.

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After estimating the ARDL model (1.2.2.0.2.0), we will conduct a cointegration test at the bounds (see Table 4) to determine the existence of a long-term relationship between the variables under study.

Table 4. *Bounds cointegration test*

Null Hypothesis: No levels relationship				
Significant level	**Critical limit values**		**Satistic Test**	**Values**
	I(0)	**I(1)**		
10%	2.331	3.417	**F-Stat**	3.6621
5%	2.804	4.013		
1%	3.9	5.419		

The results of the bounds cointegration test (Table 4) show that the F-statistic value (3.6621) is greater than 10%, indicating the existence of a significant cointegration relationship. This means that the studied variables share a stable long-term relationship and that short-term adjustments are corrected to maintain it.

Assess long-term and short-term dynamics. Based on these results, the next step consists of estimation of the long-term relationship and short-term adjustments in the Moroccan model (Table 5). This analysis allows us to evaluate the effect of the electricity mix on economic growth, by defining the pace at which the economy returns to equilibrium after a temporary shock.

Table 5. *The long-term and short-term coefficients*

Variables	**Coefficient**	**Erreur Std.**	**t-stat**	**p-value**
Relationship of the long-term dynamics				
lFOSS	0.33414	0.098488	3.364967	0.0033***
lREN	0.069546	0.026725	2.602285	0.0175**
lLF	0.006263	0.006243	-1.000012	0.3299
lGFCF	0.470262	0.023390	2.005957	0.0000***
lIND	-0.002961	0.003431	-0.862888	0.3990
Intecept	5.147452	0.473438	10.87249	0.0000***
Relationship of the short-term dynamics				
lGDP(-1)	-0.621347	0.186083	-3.339081	0.0034***
LFOSS(-1)	0.208290	0.058817	3.540922	0.0038***
lREN(-1)	0.043212	0.016774	2.576067	0.0185**
lLF	-0.003892	0.003788	-1.027252	0.3172
lGFCF(-1)	0.081141	0.022285	3.632081	0.0107**
lIND	0.001840	0.001854	-0.992342	0.3335
D(lFOSS)	0.206147	0.084300	2.445391	0.0244**
D(lFOSS(-1))	-0.139385	0.086457	-1.612195	0.1234
D(lREN)	0.066025	0.014930	4.422413	0.0003***
D(lREN(-1))	-0.045147	0.012317	-3.665529	0.0016***
D(lGFCF)	0.277615	0.090830	3.056430	0.0065***
D(lGFCF(-1))	-0.144149	0.091026	-1.583592	0.1298
Intercept	3.198352	0.951296	3.362101	0.0033***
CointEq(-1)	-0.621347	0.106986	-5.807742	0.0000***

****** Significant at 1%. **Significant at 5%.*Significant at 10%.***

The results of the long-run estimates (Table 5) confirm the existence of a long-term equilibrium relationship between GDP and the explanatory variables. Via a negative and highly significant error correction term (CointEq (-1) = -0.621347; p = 0.0000), indicating that about 62% of the imbalances are corrected annually, ensuring a rapid return to equilibrium. In the long-term, the contribution of fossil fuels (lFOSS) to electricity production shows a positive and significant

impact on Morocco's GDP, reflecting the country's continued dependence on conventional fuels to support economic growth. In addition, the share of renewable energy in the electricity mix contributes positively and significantly to GDP, although their impact remains moderate, reflecting a still gradual energy transition process. The variable (lGFCF) turns out to be a major determinant of long-run economic performance, with a coefficient of 0.4702 and is significant at 1% level, suggesting its driving role in capital accumulation and economic expansion. On the other hand, the work (lLF) and the added value of the industrial sector (lIND) show no significant effects, reflecting limitations in terms of productivity and industrialization.

In the short-term, both renewable and fossil energies significantly affect GDP. Fossil energy support growth through their immediate effects. In contrast, renewables show an immediate effect, followed by a delayed negative effect, which is characteristic of technological adjustment costs. The (GFCF) continues to stimulate GDP in the short-term, while labor and industrial value added remain insignificant. This confirms the importance of capital and the energy mix in Morocco's economic dynamics.

However, further analysis is needed to confirm these relationships and understand the underlying mechanisms.

Diagnostic tests. The long-term stability of coefficients is determined by analyzing short-term dynamics. After estimating the Error Correction Model (ECM), we use the cumulative sum of recursive residuals (CUSUM) illustrated in Figure 2 to assess the stability of parameters as recommended by Pesaran & Pesaran [19] .

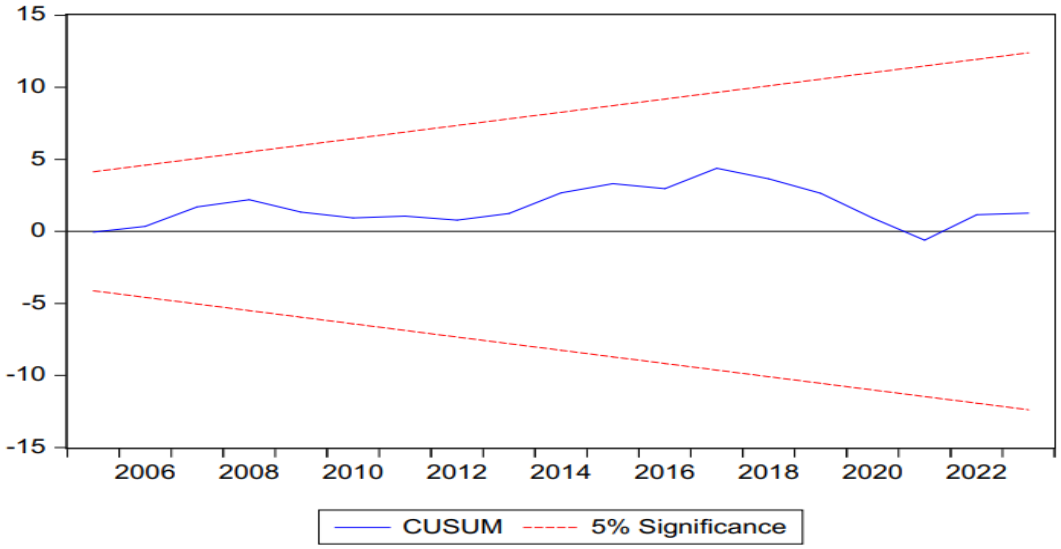


Fig. 2 *CUSUM reliability tests*

The CUSUM test applied to the Moroccan ECM model (Figure 2) shows that the cumulative process curve remains within the critical limits at 5% confidence level, confirming the stability of the Moroccan model coefficients during the study period.

Following the CUSUM test, diagnostic tests (Table 6) are performed to confirm the model's robustness.

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Table 6. *Validity tests of the Moroccan model*

Hypothesis Tests			Value
Autocorrelation	**(**Breusch-Godfrey)	T stat (p-value)	2.2822 (0.1324)
Heteroscedasticity	(Breusch-Pagan-Godfrey)	T stat (p-value)	1.8118 (0.1194)
Normality	Jarque-Bera	T stat (p-value)	0.8543 (0.6523)

The analysis of the validity tests shows that the Moroccan model (Table 6) is correctly specified. Indeed, the Breusch-Godfrey test shows a probability greater than 5% (0.1324), the Breusch-Pagan test shows a probability greater than 5% (0.1194), and the Jarque-Bera test shows a probability greater than 5% (0.6523). These results confirm the absence of autocorrelation and heteroscedasticity, as well as the normal distribution of the residuals.

Discussion

The results of the ARDL model reveal a long-term relationship, confirming that energy choices have a lasting impact on Morocco's development trajectory, in line with the literature on the energy-growth nexus [4, 6].

Fossil fuels have a positive and significant impact, highlighting the high dependence of Morocco on these sources to ensure electricity security and stimulate productive activities. In the short-term, this dependence is consistent with SDG 8 (sustained growth), even if it can cause disagreements with climate commitments. In contrast, renewable energy shows a positive long-term contribution, reflecting that the ongoing transition marked by projects like Noor solar complex and wind farms, is starting to generate economic benefits, although in a non-linear manner. This trajectory highlights the stages of technological adaptation, high initial costs, and intermittency, as emphasized by Geels [9] and the IEA [7]. In the long-term, the positive effect of renewable energy is in line with the objectives of SDG 7, which aims to ensure equitable access to clean, reliable, and modern energy, while consolidating SDG 8 through more sustainable growth. These results indicate that Morocco's energy transition is gradually producing tangible results.

At the same time, the gross fixed capital formation (GFCF) appears to be a crucial determinant of economic growth. These results are strongly linked to Morocco's energy profile, since a significant part of GFCF is devoted to electricity infrastructure, ranging from thermal power plants to solar and wind projects, as well as to network modernization. Investment in the energy sector is a key mechanism for capital accumulation and productivity growth, in line with Solow's theory [5] and IEA analysis [7].

On the other hand, labor input and added value of the industrial sector do not have significant effects, which testifies to persistent constraints in productivity and structural transformation. Economic growth is increasingly based on improving the quality and efficiency of labor rather than simply expanding the workforce, whereas industrial production only makes a significant contribution by being linked to a higher value activity and technological upgrading [20, 21, 22, 23]. In Morocco, labor productivity gains and industrial activity are not yet significant, partly because of energy inefficiencies and weak sectoral linkages [24].

Finally, the significance of the error correction term (ECM) confirms the speed of the restoration of balance following a shock, which shows that the Moroccan economic system responds directly to the fluctuations in the electricity mix.

Overall, the results show that the electricity mix is a key element of economic growth: fossil fuels remain crucial in the short-term, while renewable energy sources play an essential role in long-term growth in line with SDGs 7 and 8. This reinforces the idea that the energy transition is

not just an environmental necessity, but also a fundamental driver of sustainable development in Morocco.

Conclusion

This article examines the impact of the electricity mix on economic growth in Morocco using an ARDL model applied to the period 1990-2023. The results illustrate that energy structure plays a decisive role in the dynamics of economic growth, confirming the existence of a long-term relationship between fossil fuels, renewable energy, and economic activity. Fossil fuels remain at the heart of the Moroccan system, reflecting the country's persistent dependence on conventional sources to ensure stable electricity supply. Moreover, renewable energy sources have mainly long-term positive effects, reflecting a gradual energy transition and the gradual emergence of its economic advantages, in accordance with national strategies and international development objectives.

The study highlights the importance of GFCF, which constitutes an essential lever for the accumulation of energy productive capital. Investments in electrical infrastructure are therefore essential to stimulate growth in accordance with the theoretical foundations of Solow and SDGs 7 and 8.

Finally, the significance adjustment term confirms the ability of the Moroccan economy to quickly regain equilibrium following energy imbalances taken as a whole with approximately 62% of deviations corrected each year. The results emphasize that the energy transition is not only necessary for the environment but also a strategic factor for sustainable growth. They stress the importance of increasing investments in clean technologies, modernizing electricity infrastructure, and pursuing structural reforms with a view to reconciling energy security, economic competitiveness, and climate commitments.

This study has certain limitations. Particularly, it does not take into account structural breaks caused by energy reforms and external shocks, which could affect the stability of the estimated relationship. In the future, research could incorporate structural break tests to rigorously assess the impact of energy reforms and external shocks on the energy-growth nexus.

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