International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(6), 543-547.

Dynamic Impacts of Energy Consumption on Agricultural Growth in Iran and Selected Developing Countries

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Received: 29 May 2025 **Accepted:** 26 September 2025 **DOI:** https://doi.org/10.32479/ijeep.21062

ABSTRACT

Many countries across the globe are facing difficulties in meeting energy demand in their production sectors. Non-renewable feature of fossil fuels necessitates enhancing their efficiency in all economic sectors including agriculture. Touching this goal, requires reliable evidence on the impact of energy on sectoral economic growth. This study aims at estimation of the effect of energy use on agricultural growth in selected developing and developed nations. We applied country panel data, conventional parametric and non-parametric approaches as our materials and methods. Our findings show that the impact of energy use on agricultural growth varies over time in both groups of countries indicating its dynamic influence. In addition, the non-parametric approach captures such an impact in a better manner. Keeping sustainable growth and environmental concerns in mind, agricultural energy efficiency promotion in high carbon dependent countries through technology investment is recommended.

Keywords: Energy, Environment, Non-Parametric Models, Panel Data, Developing Countries
JEL Classifications: C5, Q4

1. INTRODUCTION

Energy consumption is a pivotal determinant of agricultural productivity, particularly in oil-producing nations where the interplay between energy availability and sectoral growth is complex. In countries like Iran, abundant energy resources coexist with significant inefficiencies and infrastructural challenges that affect agricultural development. Despite possessing the world's second-largest proven natural gas reserves, Iran faces persistent energy deficits and inefficiencies that hinder the optimal utilization of energy in agriculture.

In 2023, Iran experienced a record-high gas-flaring rate of 20.4 billion cubic meters, marking a 19% increase from the previous year and highlighting the underutilization of associated gas due to outdated infrastructure and insufficient investment. This inefficiency is compounded by an aging power generation infrastructure, with approximately 80% of steam power plants and 11% of gas power plants exceeding 30 years of age, leading to substantial energy losses. Consequently, Iran's energy consumption per capita is more than double the global average, reflecting systemic inefficiencies rather than overconsumption.

The agricultural sector, heavily reliant on energy-intensive processes such as irrigation, mechanization, and fertilizer application, is particularly affected by these energy constraints. Studies have shown that energy use efficiency varies significantly across crops in Iran, with some, like saffron, exhibiting negative energy balances due to traditional farming practices. This disparity underscores the need for targeted interventions to enhance energy efficiency in agriculture.

In contrast, developing countries exhibit diverse energy consumption patterns. While some, like China, have made significant strides in renewable energy adoption, others continue to face challenges related to energy access and infrastructure.

For instance, China's rapid shift towards electrification, with electric vehicles comprising 50% of new car sales, has led to a projected reduction in global crude oil demand by around 6 million barrels per day. However, many developing nations still grapple with energy shortages and inefficiencies that impede agricultural growth.

This study employs panel data analysis to examine the impact of energy consumption on agricultural growth in selected developing countries, with a particular focus on Iran. By integrating recent data and addressing the unique challenges faced by oil-producing nations, this research aims to provide insights into the complex relationship between energy use and agricultural growth, informing policy decisions that promote sustainable growth in the sector.

The remainder of the paper is organized as follows. Next section presents literature review. Materials and methods are provided in Section 3. Our findings are discussed in Section 4; Finally, Section 5 concludes and gives some policy implications.

2. LITERATURE REVIEW

Recent research underscores the vital role of energy consumption in promoting agricultural growth, particularly in developing economies. According to Ghodsi and Stehrer (2016), increased access to electricity and mechanized tools directly correlates with higher agricultural yields in Iran. Similarly, Karimi et al. (2018) emphasize that energy subsidies have led to over-reliance on fossil fuels, thus hampering the adoption of more efficient and sustainable energy sources.

Studies by Majeed et al. (2023) show that modern irrigation systems powered by renewable energy can significantly reduce water and energy waste, enhancing both crop output and environmental sustainability. Further, research by Amini et al. (2023) suggests that integrating solar energy into agricultural processes could address regional disparities in energy access, especially in Iran's rural provinces.

International studies support these findings. For instance, Asumadu-Sarkodie and Owusu (2017) report that in many developing countries, improvements in energy infrastructure positively affects agricultural productivity. Likewise, the World Bank (2020) highlights that targeted energy policies and investment in renewable energy can transform subsistence agriculture into commercial-scale operations. Xiong et al. (2015) investigated the relationship between energy consumption and economic growth in Kazakhstan, highlighting the need for a low-carbon development strategy. Esen and Bayrak (2017) analyzed panel data from net energy-importing countries, finding that energy consumption supports economic growth, emphasizing the importance of energy imports for economic stability. Khan and Ozturk (2021) examined Saudi Arabia's carbon emissions from 1985 to 2021, revealing a long-term relationship between energy consumption and economic growth, with significant implications for environmental policy. Bastola and Sapkota (2015) investigated the relationships among energy consumption, pollution emission, and economic growth in Nepal, highlighting the challenges in balancing energy use with environmental sustainability. Begum et al. (2015) studied CO_2 emissions, energy consumption, economic, and population growth in Malaysia, providing insights into the dynamics affecting agricultural productivity. Finally, Pata and Terzi (2017) conducted a multivariate causality analysis between energy consumption and growth in Turkey, offering insights into the energy-agriculture-growth relationship.

Additional recent research contributes further evidence. Azadi et al. (2020) analyze the potential of bioenergy in Iran's agricultural sector, concluding that biomass energy could be a sustainable alternative to fossil fuels. Mousavi et al. (2023) evaluate the effectiveness of energy use in Iranian greenhouses, noting that optimized energy systems lead to significant cost reductions and yield improvements.

In sum, these post-2015 studies collectively argue for a comprehensive energy-agriculture strategy that balances productivity with sustainability, especially in resource-rich but infrastructure-challenged nations like Iran. Moreover, the reviewed studies underscore the complex and context-dependent relationship between energy consumption, economic growth, and agricultural development. While energy consumption is generally positively associated with economic growth, the impact on agriculture varies based on technological, infrastructural, and policy factors. Notably, oil-producing countries like Iran face unique challenges due to energy inefficiencies and infrastructural constraints, which can hinder agricultural productivity despite abundant energy resources.

3. MATERIALS AND METHODS

In terms of methods applied, previous studies have employed various econometric techniques to explore the relationship between energy consumption and economic (agricultural) growth. These include the GMM (generalized method of moments) (Jian et al., 2019; Adams et al., 2016), VAR (Vector Autoregressive) (Ouyang and Li, 2018; Chen, 2012), VECM (vector error correction model) (Omri, 2013), and the ARDL (autoregressive distributed lag model) (Chandio et al., 2019). Among these, VECM and cointegration analyses are the most frequently applied, particularly in studies using non-stationary panel data.

Unlike most of the previous works, this study utilizes panel data to assess the dynamic relationship between energy consumption and agricultural growth. Panel data's combined time-series and cross-sectional dimensions enhance the robustness and efficiency of statistical estimations. We apply both the conventional parametric method and the well-featured non-parametric method as well. This allows us examining how the reliance of agricultural growth on energy use evolves over time, with a dual focus on achieving sustainable growth and reducing carbon emissions.

3.1. Parametric (Conventional) Model

The parametric or conventional model, which is used as a base model, is specified as follows:

$$LnAGV_{it} = \alpha_i + \beta_1 \, LnA\,EC_{it} + \beta_2 \, LnALF_{it} + \beta_3 \, LnACF_{it} + \beta_4 \, LnRAI_{it} + U_{it} \quad (1)$$

Here α_i represents unobserved time-invariant cross sectional (country) heterogeneity, β_s are regression coefficients and U denotes residual term, which is supposed to capture proper statistical characteristics. Subscripts i (1,2..,10)[1] and t (2000-2023) represent countries and time, respectively. Table 1 demonstrates all information about the variables.

3.2. Time Varying Coefficients (Dynamic) Model

To capture dynamic relationships within panel data, Li et al. (2011) developed the local linear dummy variable estimation (LLDVE) method, which allows for the estimation of time-varying coefficients. Building on this foundation, Silvapulle et al. (2017) further advanced the method, confirming its effectiveness in modeling non-static relationships across economic variables. Owing to its superior capacity to reflect temporal variation, this study applies the LLDVE technique to investigate how energy consumption (among other well-known growth drivers) influence agricultural growth over time. The empirical strategy is grounded in a fixed-effects panel data model, specified as follows:

$$LnAGV_{it} = \gamma_t + X_{it}^T \beta_t + \alpha_i + \varepsilon_{it} \quad (2)$$

$$X_{it} = (LnAEC_{it}, LnALF_{it}, LnACE_{it}, LnRAI_{it}) \quad (3)$$

$$\beta_t = (\beta_{t1}, \beta_{t2}, \beta_{t3}, \beta_{t4}) \quad (4)$$

Where γ_t denotes time heterogeneity, α_i and subscripts i and t are the same as defined earlier.

In order to equation (2) be identified, it's generally assumed that: $\sum_1^N \alpha_i = 0$.

3.3. Data

This study utilizes annual data from 10 developing countries over the period 2000-2023, resulting in a balanced panel comprising 10 cross-sectional units and 24 time-series observations for each unit.

Table 2 depicts descriptive statistics of the variables. As expected, Brazil's agricultural energy consumption remains the highest in the sample. In 2023, Brazil's agricultural sector consumed 14.1 MTOE, marking the highest level recorded during this period. This reflects a consistent upward trend from 2000 onwards. In Iran, the agricultural sector accounts for 15.9% of the total energy consumption. Turkey's agricultural energy consumption has generally increased over 2000-2023, driven by growing agricultural production and export. Electricity consumption in Turkey's agriculture has seen a particularly sharp increase due to increased use of irrigation pumps and other electrical equipment.

1 Based on data availability, ten developing countries including: Iran, Brazil, Egypt, Pakistan, India, Turkey, Saudi Arabia, South Africa, Algeria and Ghana are selected as our study sample

4. RESULTS AND DISCUSSION

Numerous analyses exploring the link between energy consumption and economic growth and relying on panel data often involve variables that are not stationary. This can result in nonsensical regressions. To prevent such situations, it is crucial to assess whether error terms are independent across cross sectional units before testing for stationarity and long-term association among the variables. In this paper, before conducting unit root tests, we examined whether the cross-sectional units (countries) are correlated. Since the number of countries (n = 10) is smaller than the time periods (T = 24), the Breusch and Pagan (1980) LM test was employed to determine the presence of CSD. The result of this test helps the choice of proper panel unit root tests. Traditional (so-called first-generation) unit root tests presume no cross-sectional correlation, whereas more recently introduced (so-called second-generation) tests allow for such dependencies. Table 3 presents the obtained result confirming independency of the cross sectional units.

Traditional or first generation panel unit root tests are applied in this study as we found no evidence of cross sectional dependence among our sample countries. The results of three commonly used tests including IPS (Im, Pesaran, Shin), LLC (Levin, Lin, Chow), and HT (Harris and Tzavalis) can be seen in (Table 4). All variables are taken in natural logarithm in the models and unit root tests as well. It is obvious that all variables are nonstationary at level and must be regarded as I(1).

Considering non-stationarity of the variables, estimators of the parameters in equation (1) would be reliable if the residual term U_{it} is stationary. Table 5 shows the estimation results of this fixed effects panel regression model.

It is clear that among the variables analyzed, energy consumption has the most notable impact on agricultural growth. The elasticity of agricultural value added with respect to energy use is estimated at around 0.23, indicating that a 1% rise in energy consumption corresponds, on average, to a 0.23% increase in sector value added across the entire dataset. The arid and semi-arid climate, which dominates most of our sample countries, necessitates application of electric equipment and facilities to secure supply of required water for agricultural produce. This leads to relatively high dependence of sector to energy.

Table 1: Definition of variables

Variable	Symbol	Type	UOM*	Expected effect	Source
Agricultural energy consumption	AEC	Independent	MTOE**	Direct	World Bank, IEA
Agricultural labor force	ALF	Independent	Thousand Person	Direct or indirect	FAO
Agricultural capital formation	ACF	Independent	Million USD	Direct	FAO
Rainfall	RAI	Independent	Millimeter	Direct	FAO
Agricultural value added	AGV	Dependent	Million USD	-	FAO

*Unit of measurement, ** Million Tonnes of Oil Equivalent

Table 2: Descriptive statistics

Variable*	n	Mean	Standard version	Max	Min
AGV	240	59216	101082	605141	2861
ACF	240	147438	196595	1075098	3753
ALF	240	29397	64344	226058	406
AEC	240	53	121	124	14
RAI	240	325	25	1562	57

*Units of Measurement are reported in [Table 1]

Table 3: Breusch-Pagan LM test of cross sectional dependency

LM test	Statistic	Probability
Lagrange multiplier	5.85	0.45

Table 4: Unit root tests results

Variable	LLC		IPS		HT	
	Level	FD	Level	FD	Level	FD
LnAGV	−1.95	−5.24***	−0.64	−6.78***	−0.57	−7.23***
LnACF	−0.97	−7.44***	−1.26	−5.74***	−1.12	−3.23**
LnALF	−1.56	−4.64**	−0.77	−3.11**	−0.97	−3.96**
LnAEC	−1.33	−5.48***	−1.92	−6.17***	−1.43	−7.11***
LnRAI	−0.91	−3.43**	−0.84	−3.11**	−1.05	−3.49**

FD: First difference ** and ***denote significance at 5 and 1% levels, respectively

Table 5: Estimation result of the parametric (conventional) model

Variable	Coefficient	t-statistic	Probability
Constant	0.83	4.01	0.03
LnACF	0.11	3.89	0.04
LnALF	−0.04	−1.24	0.11
LnAEC	0.23	4.29	0.03
LnRAI	0.14	3.32	0.04

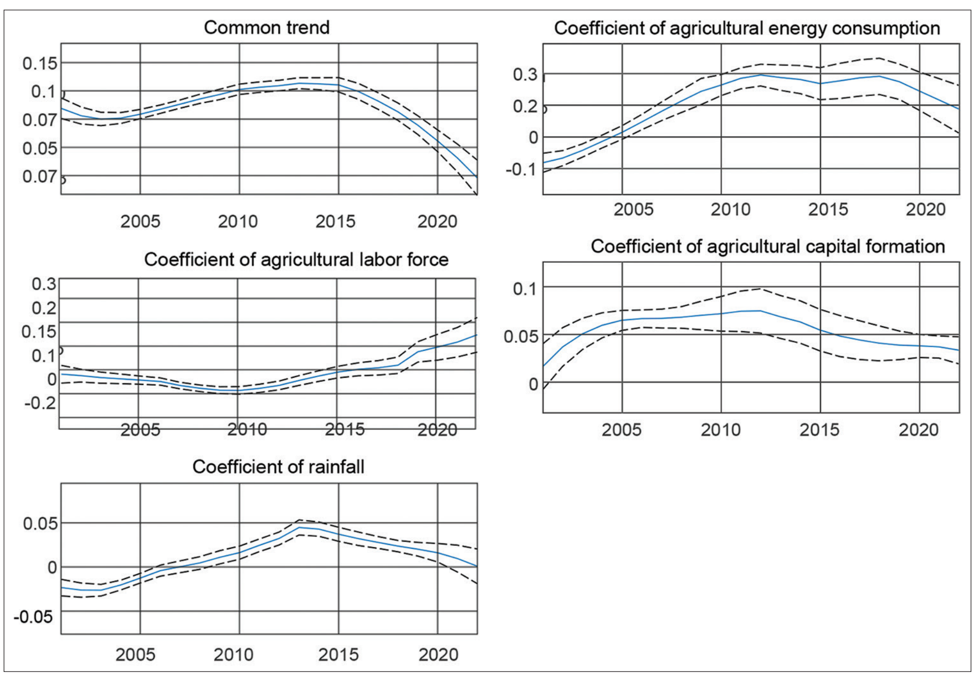
R^2=0.87, F=25.64 (<0.001), Observations=240

Rainfall and capital formation are the other important drivers of agricultural growth. In other words, a 1% increase in annual rainfall and capital formation cause, on average, a 0.14% and a 0.11% rise in sector growth, respectively. Moreover, our data does not support significant impact of labor force on agricultural growth. The R^2 measure, which shows how well the model explains the variability in agricultural growth, is at high level indicating that four selected independent variables explain 87% of the dependent variable variation. This suggests a strong explanatory power of the model. The F- statistic rejects the null hypothesis, affirming the overall statistical significance of the estimated model. All performed diagnostic checking tests including stationarity, homoscedasticity and independence of residuals, confirmed reliability of our findings.

Figure 1 presents the estimated time varying coefficients introduced in equation (4). This allows us getting better understanding of the associations among variables over a period. To show significance of our estimations, the 95% confidence interval is shown in each diagram. Coefficient of "common trend" clearly indicates two stages of growth and recession in the agriculture sector of our sample countries. Considering coefficient of "agricultural energy consumption" one can claim that energy consumption has had a positive impact of agricultural growth for nearly 16 years. This shows that energy consumption is a powerful driver of sector growth. Therefore, governments must carefully consider any reforming policy targeting fossil fuel price provided to agriculture. After 2017, this impact weakens but remains positive.

The effect of "agricultural labor force" follows negative trend until 2010, but turns into positive after 2010 and gets stronger over rest of the period. It could be attributed to the technology transfer to the

Figure 1: Time varying coefficients and their confidence intervals



sector, which enhances labor force productivity. The coefficients of two remaining variables including "agricultural capital formation" and "rainfall" show similar pattern.

In sum, we found evidence on superiority of time varying coefficient model over parametric (conventional) model in describing effect of energy consumption on agricultural growth. This finding is in line with Ren et al. (2022).

5. CONCLUSION

To examine possible dynamic impact of energy consumption on agricultural growth, we applied time varying nonparametric approach along with parametric (conventional) model for a panel data set comprising 10 developing nations during 2000-2023. The nonparametric approach allows us to estimate time dependent coefficients for each independent variable.

The coefficient on "common trend" suggests that agriculture is growing in the studied countries by different rates over the period under study. The growth rate reached at its maximum (0.12) in 2015. The country-specific figures show similarities with common trend. The impact of energy consumption on agricultural growth is positive after 2005 (three quarter of the sample period). This finding carries an important policy implication. Development of new energy sources and enhancing energy efficiency by application of new technologies in the sector, results in continuous and greater growth rates in agriculture.

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