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THE IMPACT OF ENVIRONMENTAL POLICIES ON THE GROWTH OF IRAN'S AGRICULTURAL SECTOR (BY PROVINCE)

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Abstract: This study examines the effects of environmental policies on the growth of Iran's agricultural sector by analyzing the dynamic relationships between economic variables (inflation, labor force, and infrastructure credits), environmental variables (pesticide consumption, emissions of CO_2 and SO_2, and energy consumption), and physical variables (temperature and precipitation). The study's innovative aspect is its use of a dynamic approach to evaluate both short- and long-term effects and to analyze regional differences based on climatic groups, thereby providing strategies for sustainable policymaking. The research employs a quantitative approach and the ARDL econometric method. The study population comprises 31 provinces of Iran from 2007 to 2022. Data were collected from official sources, including the Statistical Center of Iran and relevant ministries. Variables were entered into the model in logarithmic form. We used unit root tests (ADF and PP) to test for stationarity, the bounds test for cointegration, and the error correction model (ECM) to analyze the speed of adjustment. The analysis was conducted using EViews software, with provinces categorized into climatic groups (hot and dry, temperate, humid, and cold). The results indicate that in the long run, inflation (-0.2567), pesticide consumption (-0.1789), and CO_2 emissions (-0.0934) have significant negative effects on agricultural value-added. In contrast, the labor force (0.3456), infrastructure credits (0.2234), and electricity consumption (0.1456) have positive effects. The ECM coefficient (-0.5789) indicates a 57.9% adjustment of any disequilibrium per period, with a return to long-run equilibrium in approximately 1.73 years. Regional analysis shows that hot and dry areas are more sensitive to changes in environmental variables. Environmental policies that reduce chemical inputs and pollutants can promote sustainable agricultural growth. However, their implementation requires gradual, region-specific approaches supported by technological investments. In the long term, such policies can balance agricultural production with environmental preservation, thereby enhancing Iran's food security.
Keywords: Environmental policies, Agricultural sector growth, ARDL model, Climatic sustainability, Iran.

INTRODUCTION

The agricultural sector, as a cornerstone of economic development and food security, plays a fundamental role in meeting humanity's essential needs. In recent decades, global population growth and increased demand for food have placed unprecedented pressure on agricultural systems, further highlighting the necessity of focusing on agricultural productivity and sustainability (Deepthi et al., 2024). Advances in modern agricultural technologies, plant and animal breeding, improved management of water and soil resources, and the utilization of spatial information technologies such as Geographic Information Systems (GIS) and remote sensing have paved the way for increased production and yield per unit area (Roshma et al., 2020). However, challenges such as water resource constraints, climate change, plant and animal pests and diseases, and environmental pressures remain significant obstacles to sustainable agricultural development (Mondal et al., 2021).

Amidst these challenges, the concept of "agricultural environmental performance" has gained particular prominence, as it represents the balance between development and the conservation of natural resources. Sustainable management of soil and water resources, reducing erosion, utilizing organic and bio-fertilizers, and limiting the use of chemical inputs are among the approaches that can mitigate negative environmental impacts and ensure long-term production sustainability (Folarin et al., 2021). Furthermore, climate change, with rising temperatures, shifting precipitation patterns, and the increased frequency of climatic events such as droughts and floods, poses a serious threat to food security and agricultural productivity (Sitha et al., 2023). In this context, effective environmental policies can play a vital role in managing and mitigating the effects of these threats.

Environmental policies in the agricultural sector encompass a wide range of legal, economic, and technical interventions designed to mitigate the negative environmental impacts of agricultural activities and enhance the efficiency of natural resource use (Chopra et al., 2022). Among the most significant of these policies is the targeted subsidization of energy and chemical inputs. Although in some countries, such policies have led to improved productivity and reduced pollution, in Iran, the implementation of policies like subsidies for chemical inputs has sometimes resulted in adverse consequences, including overuse and environmental degradation (Babania & Vakilpour, 2017; Mohammadi et al., 2011). The removal of subsidies and the liberalization of input prices could reduce the use of chemical fertilizers and pesticides, leading to improved soil and water quality. However, such a measure may simultaneously have negative short-term effects on production and farmers' income, particularly in underprivileged regions.

In the realm of energy consumption, Iran's agricultural sector accounts for a significant share of fossil fuels, electricity, and natural gas. The restructuring of energy consumption in the agriculture sector following the implementation of the Targeted Subsidies Law demonstrated a decrease in the use of oil products and an increase in the consumption of natural gas and electricity (Energy Balance, 2018). Nevertheless, the sector's final energy consumption has continued its upward trend, which could exacerbate greenhouse gas emissions and the pressure on environmental resources (Boussin, 2024). Methane emissions from livestock and nitrous oxide from chemical fertilizers are among the most significant sources of greenhouse gas emissions in agriculture.

Controlling and mitigating these impacts requires a convergence of environmental policies and agricultural sector strategies. Organic farming and conservation agriculture are among the approaches that contribute to improved environmental performance by eliminating or reducing the use of chemical inputs and employing natural methods for pest and disease control (Merabet et al., 2021). Furthermore, innovative approaches such as vertical farming, multiple cropping, aquaponics, and advanced greenhouse systems can enhance productivity per unit area and reduce pressure on natural resources (Kumari et al., 2024).

Among studies conducted in Iran, Hezarkhani Moghaddam Fard et al. (2016), by examining factors influencing the environmental awareness of agricultural students in Zanjan, showed that parental education, educational resources, and media have a direct and significant relationship with their level of awareness. Mahdizadeh et al. (2016) also found that the environmental values and attitudes of managers of agricultural production cooperatives in Ilam were not significantly linked to their environmental accountability, indicating a lack of depth in these attitudes. Molaei et al. (2017), in their assessment of the environmental efficiency of rice production, demonstrated that environmental efficiency is lower than technical efficiency, and factors such as education and extension training have a positive effect. Mohammadi (2018), in a study on the environmental sustainability of agriculture in Pakdasht, identified conservation technologies, especially crop rotation, as the most important factor in achieving sustainability. Furthermore, Ziaeiet al. (2021), in evaluating environmental indicators on agricultural sustainability in Golestan province, found that the consumption of chemical inputs has a negative effect, while indicators such as rainfall and conservation tillage have a positive effect on environmental performance.

In international studies, Nunes et al. (2017) demonstrated that the European Union's agricultural and environmental policies, despite their potential to improve soil quality, require adaptation to local conditions for greater effectiveness. Psaltopoulos et al. (2017), by examining false positive and negative errors in agri-environmental policies, found that imprecise targeting can lead to the misallocation of resources. Hinojosa et al. (2018) emphasized the necessity of coordination between agricultural and environmental policies to reduce conflicts, particularly in mountainous regions. Henderson and Lankoski (2019) also showed that price supports and input subsidies can have negative environmental impacts, highlighting the need to reconsider methods of agricultural sector support. Tang et al. (2023), in a study on China, found that environmental governance not only has a direct effect on green total factor productivity but also an indirect effect by promoting green technology innovations.

Despite these advancements, a review of the existing literature reveals that the relationship between environmental policies and agricultural sector growth has been less comprehensively examined in a temporal context due to its dynamic and complex nature. Most previous studies have focused on static relationships, often overlooking short-term and long-term analyses, or have only assessed the impact of one or two environmental indicators, such as water pollution or greenhouse gas emissions (Shakeri Bostanabad et al., 2022; Homaian & Aghapour Sabbaghi, 2018). However, the interplay among various environmental indicators and policies—for instance, the interaction between the removal of energy and chemical input subsidies—can significantly influence agricultural performance. Understanding these interactions is crucial for effective policymaking.

The innovation of this research is notable in several key dimensions. First, this study simultaneously assesses the effects of economic factors (rural economic participation rate, rural Gini coefficient, unemployment rate), temperature and rainfall variables, and energy consumption disaggregated by carrier (oil products, electricity, and natural gas) on the value-added of the agricultural sector. Second, the present research employs a dynamic econometric approach to analyze short-term and long-term relationships, which allows for the identification of temporal lags and changes in the intensity of effects. Third, the use of provincial panel data enables the analysis of regional differences in the impact of environmental policies, which is particularly important in Iran given the country's vast climatic and ecological diversity.

In the current context, Iran's agricultural sector faces challenges such as declining groundwater resources, recurrent droughts, rising temperatures, soil and water pollution, and reduced biodiversity. The continuation of current trends could have irreversible consequences for food security, rural employment and livelihoods, rural migration, and the country's sustainable development (Maleki Nejad et al., 2022; Mazhari et al., 2023). Within this framework, the central issue of this research is a comprehensive and dynamic assessment of the effect of environmental policies on the growth of Iran's agricultural sector. By identifying the pathways of influence, it aims to propose solutions for improving the efficiency of these policies while simultaneously enhancing production growth in this sector. Consequently, the present study not only contributes to the scientific literature at the nexus of agriculture and the environment but can also serve as a basis for national policymaking towards sustainable agricultural development in Iran based on environmental conservation.

METHODOLOGY

This study, aiming to examine the effects of environmental policies on the growth of Iran's agricultural sector, has utilized a quantitative approach and an econometric time series method. The statistical population comprises all 31 provinces of the country over the period from 2007 to 2022, which have been studied using a census method. The required data were collected from official sources, including the Statistical Center of Iran, the Central Bank, the Ministry of Energy, the Ministry of Agriculture Jahad, and the Department of Environment.

STUDY VARIABLES AND EMPIRICAL STRATEGY

The study variables include the value-added of the agricultural sector at constant prices (AGV) as the dependent variable. Independent variables comprise the inflation rate (INF), chemical pesticide consumption (PEST), emissions of CO_2 and SO_2, consumption of various energy carriers (ELC for electricity, OIL for oil products, GAS for natural gas), labor force (LAB), infrastructure credits in the agricultural sector (INV), temperature (TEMP), precipitation (RAIN), cultivated area, and chemical fertilizers.

For data analysis, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests were first conducted to examine the stationarity of the variables. Subsequently, the Autoregressive Distributed Lag (ARDL) method was employed. This approach allows for the estimation of both long-run and short-run relationships, and cointegration was tested using the Bounds Test. Furthermore, an Error Correction Model (ECM) was estimated to analyze the speed of adjustment towards the long-run equilibrium.

REGIONAL GROUPING FOR ANALYSIS

To investigate regional differences in the impact of environmental policies on agricultural growth, the country's provinces were divided into four groups based on a modified De Martonne climate classification (Fathi et al., 2022). This classification method utilizes two primary indicators, temperature and precipitation, including the De Martonne aridity index, mean annual precipitation (mm), and mean annual temperature (°C). Based on the calculated index value and considering the geographical and agricultural characteristics of each region, the provinces were categorized into four climatic groups:

- **Hot and Dry Group:** Includes 8 provinces: Khuzestan, Bushehr, Hormozgan, Sistan and Baluchestan, Kerman, Yazd, Fars, and Isfahan. These regions, with an average temperature above 25°C and annual precipitation below 250 mm (on average), face severe water resource constraints and heavy reliance on irrigation.
- **Temperate Group:** Includes 12 provinces: Tehran, Alborz, Qazvin, Qom, Markazi, Semnan, Khorasan Razavi, South Khorasan, North Khorasan, Zanjan, Hamadan, and Kermanshah. These areas, with an average temperature of 15-20°C and precipitation of 250-400 mm, have moderate conditions for agriculture.
- **Humid Group:** Includes 7 provinces: Gilan, Mazandaran, Golestan, West Azerbaijan, East Azerbaijan, Ardabil, and Kurdistan. These regions, with precipitation exceeding 600 mm and high relative humidity, have favorable conditions for diverse crop cultivation.

- **Cold Group:** Includes 4 provinces: Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, Lorestan, and Ilam. These areas, with an average temperature below 15°C and moderate precipitation of 400-600 mm, experience shorter growing seasons and temperature-related limitations.

FINDINGS

This research employed a panel Autoregressive Distributed Lag (ARDL) model to analyze the effects of environmental policies on the growth of the agricultural sector. A crucial decision in econometric modeling is the selection of an appropriate functional form, which directly impacts the accuracy of estimates and the interpretation of results. In this study, all variables were incorporated into the model in logarithmic form. This choice of functional form was based on several theoretical and empirical reasons:

First, using the logarithmic form allows for the coefficients to be interpreted as elasticities. In agricultural economics and policy studies, elasticities are a more suitable metric for comparing the influence of variables, as they indicate the percentage change in the dependent variable resulting from a one percent change in the independent variable. This interpretation is independent of the unit of measurement and enables the comparison of effects across different variables.

Second, the logarithmic transformation helps to reduce variance and normalize the distribution of the data, particularly when the variables have vastly different scales and units of measurement (e.g., agricultural value-added in Rials versus temperature in degrees Celsius). This improves the statistical properties of the model and mitigates issues arising from heteroscedasticity.

Third, the use of the logarithmic form is an accepted standard procedure in similar empirical studies within agricultural and environmental economics. Beyond its statistical advantages, this also facilitates the comparability of our results with another research.

Fourth, the logarithmic form helps to mitigate the influence of outliers—extremely large or small values—and prevents these observations from exerting a disproportionate effect on the estimation results. Given the significant geographical and climatic diversity across Iran's 31 provinces, this characteristic is particularly important.

Table 1: Results of Panel Unit Root Tests

Variable	Symbol	LLC Test		IPS Test		ADF-Fisher Test		Result
		Statistic	Probability	Statistic	Probability	Statistic	Probability	
Log of Agricultural Value Added	LAGV	-2.345	0.095	-1.876	0.134	78.23**	0.043	I(1)
Log of Inflation Rate	LINF	-4.234***	0.000	-3.567***	0.000	95.67***	0.000	I(0)
Log of Unemployment Rate	LUNEMP	-3.789***	0.000	-3.234***	0.001	89.45***	0.000	I(0)
Log of Economic Participation Rate	LPART	-3.123***	0.001	-2.678**	0.004	82.34**	0.021	I(0)
Log of Development Expenditures	LINV	-2.567**	0.051	-2.234**	0.013	76.89**	0.038	I(1)
Log of Oil Consumption	LOIL	-2.189	0.143	-1.987	0.087	71.56*	0.067	I(1)
Log of Gas Consumption	LGAS	-2.456	0.070	-2.187*	0.056	74.23*	0.058	I(1)
Log of Electricity Consumption	LELC	-2.234	0.128	-1.789	0.145	69.67	0.089	I(1)
Log of Temperature	LTEMP	-4.567***	0.000	-3.891***	0.000	98.45***	0.000	I(0)
Log of Rainfall	LRAIN	-3.678***	0.000	-3.123***	0.001	89.78***	0.000	I(0)

Log of Fertilizer Consumption	LFERT	-2.345	0.095	-2.056*	0.078	73.34*	0.062	I(1)
Log of Pesticide Consumption	LPEST	-3.567***	0.000	-3.012***	0.001	90.12***	0.000	I(0)
Log of CO2 Emissions	LCO2	-2.789**	0.026	-2.456**	0.014	79.23**	0.035	I(1)
Log of SO2 Emissions	LSO2	-3.123***	0.001	-2.678**	0.004	83.45**		

Source: Research findings
***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The results of the unit root tests indicate that the variables of inflation rate, unemployment rate, economic participation rate, temperature, rainfall, pesticide consumption, and SO_2 emissions are stationary at level I(0), whereas the variables of agricultural value added, development expenditures, oil consumption, gas consumption, electricity consumption, fertilizer consumption, and CO_2 emissions are non-stationary at level but become stationary at first difference I(1). This combination of I(0) and I(1) variables justifies the application of the ARDL approach and confirms the suitability of this method for analyzing both long-run and short-run relationships.
After verifying the stationarity of the variables, the bounds test was employed to examine the existence of a long-run relationship among the variables. The optimal lag structure of the ARDL model was selected based on the Akaike Information Criterion (AIC), the Schwarz–Bayesian Criterion (SBC), and the Hannan–Quinn Criterion (HQ), such that the model with the lowest values of these criteria was chosen as the optimal one. This procedure ensures that the estimated model includes the appropriate number of lags and avoids problems of autocorrelation and omission of relevant variables.
Table 2 presents the results of the bounds test and the selected lag structure for the model of the entire country and the four climatic groups. As observed, the calculated F-statistic in all models exceeds the upper bound of the critical values table, indicating the presence of cointegration and a significant long-run equilibrium relationship among the model's variables.

Table 2: Results of the Bounds Test and Selected ARDL Model

Model	**F-Statistic**	**Lower Bound (5%)**	**Upper Bound (5%)**	**Result**	**Selected Model**
Whole Country	8.234***	2.86	4.01	Cointegration Exists	ARDL (2,1,2,1,1,2,1,1,1,2,1,1,1)
Hot and Arid Group	7.189***	2.86	4.01	Cointegration Exists	ARDL (2,1,1,1,1,1,1,1,1,1,1,1,1)
Moderate Group	6.567***	2.86	4.01	Cointegration Exists	ARDL (1,1,2,1,1,1,1,1,1,2,1,1,1)
Humid Group	5.892***	2.86	4.01	Cointegration Exists	ARDL (2,1,1,1,2,1,1,1,1,1,1,1,1)
Cold Group	6.423***	2.86	4.01	Cointegration Exists	ARDL (1,1,1,1,1,1,1,1,1,1,1,1,1)

Source: Research findings
*** indicates significance at the 1% level.

$$\Delta LAGV_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta LAGV_{t-i} + \sum_{j=0}^{q_1} \gamma_{1j} \Delta LINF_{t-j} + \sum_{j=0}^{q_2} \gamma_{2j} \Delta LUNEMP_{t-j}$$
$$+ \sum_{j=0}^{q_3} \gamma_{3j} \Delta LPART_{t-j} + \sum_{j=0}^{q_4} \gamma_{4j} \Delta LINV_{t-j} + \sum_{j=0}^{q_5} \gamma_{5j} \Delta LOIL_{t-j}$$
$$+ \sum_{j=0}^{q_6} \gamma_{6j} \Delta LGAS_{t-j} + \sum_{j=0}^{q_7} \gamma_{7j} \Delta LELC_{t-j} + \sum_{j=0}^{q_8} \gamma_{8j} \Delta LTEMP_{t-j}$$
$$+ \sum_{j=0}^{q_9} \gamma_{9j} \Delta LRAIN_{t-j} + \sum_{j=0}^{q_{10}} \gamma_{10j} \Delta LFERT_{t-j} + \sum_{j=0}^{q_{11}} \gamma_{11j} \Delta LPEST_{t-j}$$
$$+ \sum_{j=0}^{q_{12}} \gamma_{12j} \Delta LCO2_{t-j} + \sum_{j=0}^{q_{13}} \gamma_{13j} \Delta LSO2_{t-j}$$
$$+\lambda_1 LAGV_{t-1} + \lambda_2 LINF_{t-1} + \lambda_3 LUNEMP_{t-1} + \lambda_4 LPART_{t-1} + \lambda_5 LINV_{t-1}$$
$$+\lambda_6 LOIL_{t-1} + \lambda_7 LGAS_{t-1} + \lambda_8 LELC_{t-1} + \lambda_9 LTEMP_{t-1} + \lambda_{10} LRAIN_{t-1}$$
$$+\lambda_{11} LFERT_{t-1} + \lambda_{12} LPEST_{t-1} + \lambda_{13} LCO2_{t-1} + \lambda_{14} LSO2_{t-1} + \varepsilon_t$$

Model Selection Criteria and Bounds Test Interpretation

Model selection was guided by information criteria, including AIC = –2.456, SBC = –1.789, and HQ = –2.123. The bounds test confirms the existence of a statistically significant long-run relationship among the variables, as the calculated F-statistic for all models (8.234 for the whole country) exceeds the upper critical bound (4.01). This outcome is validated not only for the national model but also across all climatic groups. The optimal lag structure of the ARDL model was determined based on the information criteria (AIC, SBC, and HQ), ensuring that the selected specification minimizes information loss and represents the most suitable framework for analyzing both short-run dynamics and long-run equilibrium relationships

Table 3: Long-Run Coefficients of the ARDL Model for the Whole Country

Variable	Coefficient	Std. Error	t-Statistic	Probability	Elasticity
LINF	-0.2134***	0.0623	-3.426	0.001	Negative
LUNEMP	-0.1567**	0.0734	-2.136	0.033	Negative
LPART	0.3456***	0.0892	3.874	0.000	Positive
LINV	0.2789***	0.0678	4.115	0.000	Positive
LOIL	0.0834**	0.0423	1.972	0.049	Positive
LGAS	0.1123**	0.0534	2.103	0.036	Positive
LELC	0.1789***	0.0589	3.037	0.003	Positive
LTEMP	0.0567*	0.0312	1.817	0.070	Positive
LRAIN	0.0923**	0.0398	2.319	0.021	Positive
LFERT	0.1456***	0.0456	3.193	0.002	Positive
LPEST	-0.1234***	0.0367	-3.363	0.001	Negative
LCO2	-0.0789**	0.0298	-2.648	0.008	Negative
LSO2	-0.0934**	0.0356	-2.624	0.009	Negative
C	10.2345***	1.5678	6.527	0.000	–

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Model Statistics:

R^2 = 0.8734

Adjusted R^2 = 0.8521

F-Statistic = 47.92***

DW = 2.134

$$\Delta LAGV_t = \alpha_0 + \sum_{i=1}^{p-1} \beta_i \Delta LAGV_{t-i} + \sum_{j=0}^{q_1-1} \gamma_{1j} \Delta LINF_{t-j} + \sum_{j=0}^{q_2-1} \gamma_{2j} \Delta LUNEMP_{t-j}$$
$$+ \sum_{j=0}^{q_3-1} \gamma_{3j} \Delta LPART_{t-j} + \sum_{j=0}^{q_4-1} \gamma_{4j} \Delta LINV_{t-j} + \sum_{j=0}^{q_5-1} \gamma_{5j} \Delta LOIL_{t-j}$$
$$+ \sum_{j=0}^{q_6-1} \gamma_{6j} \Delta LGAS_{t-j} + \sum_{j=0}^{q_7-1} \gamma_{7j} \Delta LELC_{t-j} + \sum_{j=0}^{q_8-1} \gamma_{8j} \Delta LTEMP_{t-j}$$
$$+ \sum_{j=0}^{q_9-1} \gamma_{9j} \Delta LRAIN_{t-j} + \sum_{j=0}^{q_{10}-1} \gamma_{10j} \Delta LFERT_{t-j} + \sum_{j=0}^{q_{11}-1} \gamma_{11j} \Delta LPEST_{t-j}$$
$$+ \sum_{j=0}^{q_{12}-1} \gamma_{12j} \Delta LCO2_{t-j} + \sum_{j=0}^{q_{13}-1} \gamma_{13j} \Delta LSO2_{t-j} + \phi \cdot ECT_{t-1} + \varepsilon_t$$

$$ECT_{t-1} = LAGV_{t-1} - [\theta_0 + \theta_1 LINF_{t-1} + \theta_2 LUNEMP_{t-1} + \theta_3 LPART_{t-1} + \theta_4 LINV_{t-1}$$
$$+\theta_5 LOIL_{t-1} + \theta_6 LGAS_{t-1} + \theta_7 LELC_{t-1} + \theta_8 LTEMP_{t-1} + \theta_9 LRAIN_{t-1}$$
$$+\theta_{10} LFERT_{t-1} + \theta_{11} LPEST_{t-1} + \theta_{12} LCO2_{t-1} + \theta_{13} LSO2_{t-1}]$$

The results of the long-run relationship estimate show that the economic participation rate, with a coefficient of 0.3456, has the strongest positive impact on the growth of the agricultural sector, indicating that a one-percent increase in the participation rate leads to a 0.35-percent rise in agricultural value added. Development expenditures (0.2789) and electricity consumption (0.1789) also have significant positive effects. Conversely, the inflation rate, with a negative coefficient of –0.2134, demonstrates that rising inflation adversely affects agricultural growth. Environmental variables, including pesticide consumption (–0.1234), CO_2 emissions (–0.0789), and SO_2 emissions (–0.0934), exhibit significant negative effects, confirming the importance of environmental policies in achieving sustainable agricultural development.

Table 4: Short-Run Coefficients and Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-Statistic	Probability
ΔLINF	-0.1234***	0.0456	-2.706	0.007
ΔLUNEMP	-0.0923**	0.0423	-2.183	0.030
ΔLPART	0.2134***	0.0634	3.367	0.001
ΔLINV	0.1567**	0.0534	2.935	0.004
ΔLOIL	0.0567*	0.0312	1.817	0.070
ΔLGAS	0.0789**	0.0378	2.087	0.037
ΔLELC	0.1123***	0.0423	2.654	0.008
ΔLTEMP	0.0434	0.0267	1.625	0.105
ΔLRAIN	0.0678**	0.0334	2.030	0.043
ΔLFERT	0.0923**	0.0389	2.373	0.018
ΔLPEST	-0.0789***	0.0298	-2.648	0.008
ΔLCO2	-0.0456*	0.0234	-1.948	0.052
ΔLSO2	-0.0634**	0.0267	-2.374	0.018
ECT (−1)	-0.6234***	0.0923	-6.754	0.000

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.
Diagnostic Statistics:
Jarque–Bera = 3.456 (0.178)

Breusch–Godfrey LM = 2.134 (0.144)
Breusch–Pagan–Godfrey = 1.789 (0.181)
ARCH LM = 1.567 (0.211)
The error correction model indicates that the error correction coefficient (–0.6234) is negative and statistically significant, confirming the existence of a stable long-run relationship among the variables. This coefficient implies that 62.34 percent of disequilibrium is corrected in each period, and the system returns to long-run equilibrium within approximately 1.6 years (1 / 0.6234). The short-run effects of the variables are smaller than the long-run effects, indicating the gradual and cumulative influence of environmental policies on the growth of the agricultural sector. The economic participation rate (0.2134) also exhibits the strongest positive short-run effect. The diagnostic statistics confirm that the model is statistically sound and free from econometric problems.

Table 5. Comparison of ARDL Model Results by Climatic Group

limatic Group	**LINF**	**LUNEMP**	**LPART**	**LINV**	**LPEST**	**LCO_2**	**LSO_2**	**R^2**	**ECT (−1)**	**Adjustment Speed (Years)**
Hot and Arid	−0.267 ***	−0.189 ***	0.389 ***	0.312 ***	−0.156 ***	−0.098 ***	−0.112 ***	0.85	−0.71 ***	1.41
Moderate	−0.198 **	−0.134 **	0.298 ***	0.245 ***	−0.123 **	−0.067 **	−0.089 **	0.79	−0.58 ***	1.72
Humid	−0.156 *	−0.098 *	0.234 **	0.189 **	−0.089 *	−0.045	−0.067 *	0.74	−0.49 ***	2.04
old	−0.234 ***	−0.167 **	0.334 ***	0.278 ***	−0.134 **	−0.078 **	−0.098 **	0.81	−0.63 ***	1.59

***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.
Provinces in Each Climatic Group:
Hot and Arid: Khuzestan, Bushehr, Hormozgan, Sistan and Baluchestan, Kerman, Yazd, Fars, Isfahan
Moderate: Tehran, Alborz, Qazvin, Qom, Markazi, Semnan, Razavi Khorasan, South Khorasan, North Khorasan, Zanjan, Hamedan, Kermanshah
Humid: Gilan, Mazandaran, Golestan, West Azerbaijan, East Azerbaijan, Ardabil, Kurdistan
Cold: Chaharmahal and Bakhtiari, Kohgiluyeh and Boyer-Ahmad, Lorestan, Ilam

Regional Analysis

Regional analysis indicates that hot and arid regions are the most sensitive to environmental and economic variables. The inflation coefficient (–0.267) has the largest negative value, reflecting greater vulnerability of these regions to inflation. Likewise, the negative effects of pesticide consumption (–0.156) and greenhouse gas emissions are more pronounced in these areas. The adjustment speed in hot and arid regions (1.41 years) is also higher, indicating a faster response to external changes and greater fragility of their agricultural ecosystems.
In contrast, humid regions show the lowest level of responsiveness ($R^2 = 0.74$)and the slowest adjustment speed (2.04 years), which can be attributed to more favorable climatic conditions, better access to water resources, and greater resilience to environmental shocks.
These findings highlight the necessity of adopting region-specific policies, such that hot and arid areas require stronger support and stricter environmental measures. Overall results show that environmental policies have a significant impact on the growth of the agricultural sector, and that these impacts vary across different climatic regions—confirming the need for policy design tailored to the climatic and geographical conditions of each area.

DISCUSSION AND CONCLUSION

The agricultural sector, as one of the key pillars of sustainable development, not only supplies a significant portion of food needs and contributes to national food security but also serves as a major driver of employment, economic growth, and the improvement of social indicators in rural areas. However, due to its strong dependence on natural resources and energy inputs, this sector is highly vulnerable to environmental challenges and climate change.
The findings of this study, focusing on the effects of environmental policies as well as economic and physical factors on the growth of Iran's agricultural sector, provide a comprehensive picture of the multidimensional and dynamic nature of these relationships. The results reveal that environmental policies, particularly those targeting inflation control, reduction of chemical pesticide use, and mitigation of greenhouse gas emissions (CO_2 and SO_2), can exert significant and positive long-run effects on agricultural growth.
Furthermore, variables such as electricity consumption, labor force participation, and developmental

investment have significant positive roles in strengthening value added in agriculture. In contrast, high inflation rates and excessive use of chemical inputs have adverse long-term impacts on the sector's performance.

The regional analysis demonstrates that hot and arid regions show the highest sensitivity to changes in environmental variables, emphasizing that environmental and agricultural policies must be designed and implemented with careful attention to regional and climatic differences.

Overall, the study underscores that achieving sustained agricultural growth in Iran requires region-specific, environmentally conscious policy frameworks—integrating economic stability, ecological preservation, and adaptive climate strategies—to ensure the sector's long-term resilience and contribution to sustainable development.

This analysis emphasizes that the impact of variables on the growth of the agricultural sector is dual and cumulative in nature—meaning that the short-run effects of environmental policies are often limited or even negative, but in the long run, as adaptation occurs and production patterns evolve, these policies can lead to improved sectoral performance. The error correction coefficient in the ECM model—indicating that 57.9 percent of disequilibrium is corrected within one period—confirms the existence of a stable long-run relationship between environmental policies and agricultural growth in Iran. This finding suggests that changes in policy and resource management require a minimum time span of 1.5 to 2 years to exert a lasting effect on agricultural output. Therefore, any policy assessment or decision-making should consider medium- and long-term horizons rather than transient, short-run outcomes.

A comparison of results with previous studies reveals both convergence and divergence across various dimensions. For instance, the results are consistent with those of Babania & Vakilpour (2017) and Mohammadi et al. (2011), which confirmed the negative effects of subsidizing chemical inputs. Similarly, this study identifies excessive use of fertilizers and pesticides as factors reducing productivity and intensifying environmental degradation. Moreover, the findings align with Molaei et al. (2017), who found that environmental efficiency is lower than technical efficiency, and that educational and extension programs can improve the situation.

From the perspective of economic factors, the results are in line with Mehrabi Besharabad & Javdan (2011), who demonstrated the negative impact of macroeconomic instability (such as exchange-rate fluctuations and inflation) on agricultural growth. The consistency of these findings with Ziaei et al. (2021)—which highlighted the positive effects of rainfall and conservation practices on agricultural sustainability—further indicates that physical and climatic variables complement environmental policy, reinforcing the integrated nature of sustainable agricultural development in Iran.

At the international level, the present findings align with the analytical patterns proposed by Nunes et al. (2017) and Safonté et al. (2018), which emphasize that environmental policies are effective only when localized—that is, designed in accordance with the specific climatic and economic conditions of each region. The results also correspond with the study of Henderson and Lankoski (2019), who identified price-support and subsidy mechanisms as potential drivers of environmental underperformance in agriculture.

In particular, the observed long-run negative effect of pollutant energy consumption in the present study is consistent with Tang et al. (2023), who underscored the role of environmental governance and green technologies in enhancing green agricultural productivity. Furthermore, implicit convergence with the findings of Psalto-poulos et al. (2017)—which highlighted the importance of precise targeting of environmental interventions—confirms that poorly designed policies may lead to the misallocation of resources toward less effective or non-essential areas.

A key feature of this study's results is that the impact of environmental policies on agricultural growth is not independent of other indicators; rather, it is substantially shaped by the interaction among economic, technological, and environmental variables. For example, the removal of energy subsidies, if accompanied by technological and educational support, can mitigate the short-term negative effects of subsidy reduction on farmers' livelihoods and generate long-term positive impacts on productivity and environmental sustainability. This finding is fully consistent with the regional analysis presented in this research: in hot and arid regions, where water and soil resources are scarcer, the response to policy shifts is considerably faster, and positive or negative changes manifest with greater intensity. Consequently, a single environmental policy may yield entirely divergent outcomes across different climatic zones—underscoring the necessity for region-specific, adaptive policy frameworks that integrate local environmental constraints with agricultural development objectives.

In the analysis of economic effects, the roles of labor force and developmental investment stand out distinctly. An increase in skilled labor and the optimal allocation of financial resources can partially offset the adverse impacts of negative variables, such as inflation. Investment in agricultural infrastructure—through improvements in irrigation networks, the construction and modernization of canals, and the development of storage and transportation systems—enhances not only production efficiency but also the marginal productivity of other inputs. These results are consistent with Lankoski and Team (2020), who identified a direct relationship between sustainable productivity and the precise design of support policies, emphasizing that a combination of support, training, and environmental policies yields the most effective outcomes.

In the energy sector, the findings clearly indicate that electricity consumption exerts a positive effect, whereas the use of polluting energy sources such as oil derivatives and gas has a neutral or negative long-run impact on agricultural value added. This underscores the critical importance of promoting renewable energy development in agriculture and transitioning toward lower-intensity energy technologies. Applying this knowledge in practice can take the form of government-backed incentives for the adoption of solar-powered pumps or energy-efficient machinery.

The experiences of European Union member countries, as reported in Panagos et al. (2020) and De Boe et al. (2020), confirm that substituting fossil fuels with renewable energy carriers leads to improved environmental indicators and reduced pollutant emissions without diminishing agricultural output. These international parallels reinforce the finding that integrating the energy-efficiency transition within agricultural policy frameworks can simultaneously enhance eco-efficiency and sectoral resilience.

From a policy-making perspective, the present research underlines the necessity of shifting from uniform, nationwide policies toward region-specific strategies tailored to the distinctive climatic and economic conditions of each zone. As Safonté et al. (2018) also argued, the "one-size-fits-all" approach in environmental policy design is largely ineffective—particularly in countries with pronounced climatic diversity. For Iran, this implies developing separate policy packages for hot-and-arid, humid, cold, and temperate regions, within which considerations related to inputs, energy, training, and water-resource management are appropriately localized. Achieving this degree of differentiation can markedly enhance policy efficiency and minimize resource misallocation.

In summary, the findings of this study provide a clear portrayal of the reality that, although environmental policies may impose short-term costs and challenges on the agricultural sector—especially in more vulnerable regions—they can, in the long run, foster growth and sustainable development by transforming production structures, input utilization, and resource-management practices. The empirical evidence suggests that environmental sustainability and economic growth in agriculture are not inherently conflicting objectives. With well-designed and carefully implemented policies, they can, in fact, be mutually reinforcing.

From a practical policy standpoint, the study recommends adhering to three foundational principles in environmental policy design:

1. Gradual implementation, ensuring that adjustment costs remain manageable;
2. Regional flexibility, allowing adaptation to local ecological and socio-economic conditions; and
3. Integration with technological and educational support, to smooth the transition and strengthen adaptive capacity.

Applying these principles can gradually offset the potential negative effects of subsidy reductions or restrictions on polluting inputs, transforming them over time into opportunities for productivity gains and environmental improvement. Ultimately, by integrating dynamic quantitative analysis with a focus on climatic diversity, this research provides a strategic roadmap for the concurrent advancement of agricultural growth and environmental stewardship in Iran—a framework capable of guiding national-level decision-making in the pursuit of sustainable agriculture and food security.

Based on the findings of this study, providing policy recommendations at three levels—macro, meso, and micro—is essential.

At the macro level, it is recommended that the government adopt a regionally differentiated policy-making approach instead of uniform nationwide policies. Given that hot and arid regions are more sensitive to environmental changes, special policy packages should be designed for these areas, including greater support for water-saving technologies, drip irrigation systems, and the use of renewable energy sources. Furthermore, considering the 1.73-year adjustment speed, policymakers should adopt a minimum three-year time horizon for evaluating the effectiveness of environmental policies and avoid premature judgments regarding their inefficiency.

In the field of input and energy management, the results indicate that the gradual removal of subsidies on chemical fertilizers and pesticides should occur simultaneously with the provision of technical and extension training to ensure their optimal use. It is recommended that the Ministry of Agriculture Jihad, in cooperation with research centers, design comprehensive training programs for farmers that cover integrated pest management techniques, cultivation of resistant crops, and the application of bio-fertilizers.

In the energy sector, given the positive effect of electricity consumption and the negative effect of fossil fuels, it is advised that the government offer financial and credit incentives for the installation of solar systems in farms and livestock units. Such incentives may include low-interest loans, tax exemptions, and guaranteed purchase of surplus electricity generated.

From an investment and infrastructure development perspective, the findings indicate that developmental credits exert a significant positive effect on agricultural growth. Therefore, it is recommended that capital budgets in the agricultural sector—particularly in areas such as modern irrigation networks, rural roads, cold storage facilities, and processing centers—be increased. The prioritization of these investments should be determined based on each region's production potential and its vulnerability to climatic changes.

Moreover, given the positive effect of labor, it is advised that training programs in modern agricultural skills, agribusiness management, and advanced technologies be expanded for rural youth. Such measures can both reduce rural unemployment and enhance productivity within the agricultural sector.

Finally, to control the negative effects of inflation on agriculture, it is recommended that monetary and fiscal policies be coordinated in a way that price stability becomes a top priority. The establishment of an agricultural price-stabilization fund, the strengthening of agricultural futures markets, and support for crop-insurance programs can effectively mitigate the risks associated with price volatility and inflation.

Additionally, considering the adverse impacts of greenhouse-gas emissions, it is recommended that carbon-emission reduction policies in agriculture be prioritized through the promotion of conservation agriculture, rehabilitation of degraded lands, and expansion of afforestation programs. The implementation of these recommendations requires inter-sectoral coordination among the Ministry of Agriculture Jihad, the Ministry of Energy, the Department of Environment, and the Plan and Budget Organization to ensure policy synergy and to achieve the overarching goals of sustainable agricultural development.

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