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Nexus between Energy Intensity, CO_2 Emissions and Food Security: Asymmetric and Symmetric View from Kazakhstan

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ABSTRACT

The aim of this study is analyzed nexus between energy intensity, CO_2 emissions with food security in Kazakhstan. As dependent Food security indicator food production index and for energy intensity indicator Energy intensity level of primary energy were taken. As socio-economic indicators GDP per capita and population growth are taken. Data cover 2000-2021 years and extracted from World Bank Data and Worldometers. As research methods Nonlinear Autoregressive Distributed Lag (NARDL) Analysis and Linear Autoregressive Distributed Lag (ARDL) were applied. According to NARDL method, Fossil CO_2 emissions and GDP per capita found to be main factors from selected ones to affect food production index positively. CO_2 emissions (total) have positive effect on Food production index too. According to ARDL method, change in population correlated positively with Food Production index in long term. Energy intensity impacts negatively in short term and positively in long term on Food Production Index. Results imply that in Food production ecofriendly methods and new technology should be prioritized.

Keywords: Energy Intensity, CO_2 Emissions, Food Production Index, Food Security, Economic Development
JEL Classifications: I15, L66, C1

1. INTRODUCTION

Food security is a term used to describe the ability of all individuals to obtain sufficient physical and economic access to safe and nutritious food that meets their dietary needs and preferences for an active and healthy lifestyle (WFS, 1996). Back in the old days, the concept of food security appeared in the 1970s for developing countries, but now in modern realities it is the focus of attention not only in developing but also in developed countries (Makombe, 2023).

The second of the 17 ambitious UN goals by 2030 is «zero hunger», which aims at preventing hunger, ensuring food security, improving nutrition and promoting sustainable agriculture (UN, 2015). Between 2019 and 2021, the number of undernourished people in the world blew up by approximately 126 million, and the heads of international organizations have sounded the alarm that a new global food security crisis has begun (FAO et al., 2022).

Food security is a critical concern of the World Health Organization, which actively works towards addressing the challenges of hunger, food insecurity, and malnutrition (WHO, 2022). Food security is another important factor in ending poverty and inequality in income (Kakizhanova et al., 2024). To provide with sustainable food security, researchers adhere to diverse ideas and are attributed mostly to the COVID-19. The pandemic has shown us that agroecological research-action projects are very necessary. Some suggest that Sustainable fisheries and aquaculture are key sources of nutrition, livelihoods and employment (Bennett et al., 2020). Some offer the concept which called Smart food security, it is a new concept that uses digital technologies and innovative approaches to ensure a sustainable, efficient and secure food system (Aslan et al., 2024).

Thomson (2024) believes that small-scale agriculture should be given priority and should be supported by local regulatory bodies, science and the state, especially the agricultural sector in rural areas. In modern realities, when the world's population is growing, poverty is not decreasing, geopolitical instability is growing, climate change is accelerating, ensuring people have food is an important priority for countries. A healthy and educated person is always an important element for the economic development of any society. Food is the key to human health (Murkovic, 2021; Guiné et al., 2023; Fathiya, 2024). COVID-19 has shown that the food system is not perfect and that it depends on many factors (Clapp et al., 2020; Yu and Song, 2024; Junejo et al., 2024; Lau et al., 2024).

Also, the food system is also very vulnerable in terms of the climate issue, since any climate change affects the food supply (Singh et al., 2019; Pickson et al., 2023; Rehman et al., 2024). The geopolitical dimensions of global hunger must be given greater attention, including but not limited to their impacts in the fields of natural resources, trade, armed conflict and climate change (Cohen and Pinstrup-Andersen, 1999; Zhou et al., 2020).

2. LITERATURE REVIEW

If food is the source of life that gives strength to human beings, then the energy source for its production is as much air. As the world's population continues to grow, food supply and ecosystem conservation have become priorities in many ways (White and Grossman, 2010; Tian et al., 2016; Bajan et al., 2020; Szymańska and Mroczek, 2023). Thomas et al. (2024) argue that due to rising costs of living and energy prices, some segments of the population are forced to adjust their budgets, which impacts food security. Because the food sector consumes a lot of energy, Skawińska and Zalewski (2024) believe new food products have the potential to improve food and energy security. Grubler (2012) has a similar view: he considers the energy transition to be vital for sustainable food security. Corigliano and Algieri (2024) argue that the majority of energy in the food supply chain comes from fossil fuels, which means that food production contributes significantly to CO_2 emissions from fossil fuel combustion. They, also emphasize that improving energy efficiency throughout the food chain and collaboration between researchers, policymakers, industry leaders and consumers will be critical to the sustainability of food production.

CO_2 emissions are one of the atmospheric polluting factors. Since food is one of the main needs of the human race, some of the sources of energy used for its production are the source of these emissions. Hannah et al. (2022) claim that it is an important driver of climate change, responsible for about a quarter of the world's greenhouse gas emissions. Based on the standard Cobb Douglas production function, Otim et al. (2023) studied the impact of CO_2 emissions on agricultural production and found that they had a positive effect on livestock production. In a verse study, Ridzuan et al. (2020) found that in long run livestock has no impact on CO_2 emissions, and furth more, crops, fisheries and renewable energies have reduced carbon dioxide emissions, but economic growth and urbanization have increased carbon dioxide emissions. Agricultural land use carbon dioxide emissions are the most significant carbon emission from agriculture, having a huge impact on food production and atmospheric weather (Awe et al., 2024). Using quantile regression, Lin and Bin (2018) analyzed driving forces of CO_2 emissions in Chinese agriculture sector and found that there were heterogeneous effects different factors like economic growth, industrialization, financial capacity in different time sections.

Methane and nitrous oxide emissions from crop and livestock production amounted to 5.3 billion tonnes CO2eq. in 2018, up 14% from 2000 reported by FAO (2020). Shabir et al. (2023) declare that combined with the reduction of the carbon footprint of food processin, a reduction in the carbon footprint of bioplastics made from plants and recyclable materials was achieved by using renewable energy. Various measures are being taken to reduce CO_2 emissions as much as possible. Applying innovative Fourier-based econometric method, Khan et al. (2024) analyzed the impact of food production and the role of economic governance, population and economic growth as a control indicator, on food-related CO_2 emissions in China and found that food production, economic growth and population growth, food-related CO_2 emissions and environmental degradation. Tarar et al. (2023) claim that Pakistan's agrosector fossil fuel energy consumption, added extremely to economic growth, food production, but CO_2 emissions too. Using at each point the LCI analysis, Nemoto (2009) assessed CO_2 emissions associated with the distribution of food and found that CO_2 emissions from air transport of food are very high. For sustainable agricultural development, environmental safety is one of the key factors (Borowski and Patuk, 2021).

The food needs during income growth, i.e. economic development, are influenced by two forces, population growth and diet upgrade, principally to livestock products (Rask and Rask, 2011; Lem et al., 2014) agree with this, noting that urbanization will result in the growth of cities and the loss of land used or adapted for agriculture. The modern food system represents one of the greatest achievements of human society at the global/world level in terms of meeting global food needs, but it is still far from addressing human needs at the community and individual level, where many challenges exist (Carvalho and Pacheco, 2016).

Summarizing the literature review, the authors set out to test the following hypotheses:

H_0: Energy intensity positively impacts on Food security
H_1: CO_2 emissions positively impacts on Food security
H_2: Economic development has strong positive effect on Food security
H_3: Change in population has negative impact on Food security

3. METHODS

Taking into account the results of the reviews in the previous section, we examine the relationship between FPI and Fossil CO_2 emissions per capita, Change in population, Energy intensity level of primary energy, GDP per capita and Carbon dioxide (CO_2) emissions (total) in the Republic of Kazakhstan for the period 2000-2021. The definitions and measurements of all indicators are given in Table 1 below. In this case, FPI is defined by the following equation:

$$FPI_t = f(FCOE_t, CP_t, EILPE_t, GDPPC_t, CDE_t) \quad (1)$$

In the course of the study, based on the results of the ADF test, it was found that all the studied variables are stationary at level I (0) or the first differences I (1) (Table 2), only in the case of 1st difference without Intercept and trend. Therefore, for the first model, the LOG(FPIt) variable was used, which is also stationary at the level of I (1). The ARDL methodology is also used, the order of integration of variables is considered to determine the suitability of the ARDL model for research, and a maximum of one lag is selected using a special test (Table 3).

The linear ARDL model was estimated using first difference, respectively, and long-term and short-term analysis of the relationship between the variables was carried out. According to the linear ARDL model, all the independent variables were confirmed to be in a causal relationship with the changes in the dependent variable FPI. Based on the results of the first difference Granger causality test (Table 4), a linear ARDL model was estimated and long-term and short-term analysis of the relationship between the variables was performed. The nonlinear NARDL model and the linear ARDL model were estimated using logarithms and first differences, respectively, and the long-run and short-run relationship analysis between the variables was conducted. Two main models were constructed. In Model 1, the linear specification of the model was transformed into a logarithmic specification. In power model 1, the coefficients show the elasticity, giving more accurate and efficient results than the simple linear functional form:

A. In a nonlinear autoregressive distributed lag model, the NARDL procedure determines the existence of cointegration between selected variables. The bounds test tests the long-run relationships, where the NARDL structure of Model 1 is expressed in Equation 2:

$$\Delta LOG(FPI_t) = a_0 + \sum_{k=1}^{m} a_k LOG(FCOE_{t-k}) + \sum_{k=0}^{n} b_k LOG(GDPPC_{t-k}) + \sum_{k=0}^{p} c_k LOG(CDE_{t-k}) \quad (2)$$

Where, operator Δ represents the differencing operation.

B. The ARDL linear model 2 is estimated as Equation 3:

$$FPI_t = a_0 + \sum_{k=1}^{m} a_k CP_{t-k} + \sum_{k=0}^{n} b_k EILPE_{t-k} \quad (3)$$

In a linear autoregressive distributed lag ARDL model, the procedure also determines whether there is cointegration between sample variables. The bounds test examines long-run relationships, and the results of the boundedness test are presented in Table 3.

Table 1: Model variables and sources

Variables	Definitions	Sources
FPI	Food production index (2014-2016=100)	World development indicators (WDI)
FCOE	Fossil CO_2 emissions per capita (tons)	Worldometers
CP	Change in popullation (%)	Worldometers
EILPE	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	Worldometers
GDPPC	GDP per capita ($)	Worldometers
CDE	Carbon dioxide (CO_2) emissions (total) excluding LULUCF (Mt CO_2e)	World development indicators (WDI)

Source: Authors

Table 2: Noncausality tests in the sense of Granger for the vector autoregressive (1) (2000-2021)

Direction of causality	F-statistic	Prob.
FPI		
FCOE does not granger cause FPI	0.16083	0.8529
CP does not granger cause FPI	1.15296	0.3422
EILPE does not granger cause FPI	0.89478	0.4294
GDPPC does not granger cause FPI	0.88837	0.4319
INF does not granger cause FPI	0.81088	0.4630
CDE does not granger cause FPI	0.14838	0.8634

Table 3: Results of cointegration test

Model	F Statistics	Critical bounds	Decision
Model 1- NARDL (1, 0, 0, 0)	15.94604	3.1-4.84	Cointegration
Model 2- ARDL (1, 1, 1)	5.2363	3.1-4.84	Cointegration

Critical bounds are reported at 1% (***) and 10% (**) level of significance

4. DATA AND FINDINGS

4.1. Data

Author chose the food production index as main indicator of food security, as FPI definition states that it measures changes in the production of food crops that are considered edible and provide nutrients in a given year compared to a base year. This study examines the impact of the main factors on the Food production index (FDI) in the Republic of Kazakhstan. The study uses data for the period 2000 to 2021, which was obtained through the World Data Bank (WDI), ourworldindata.org. and Worldometers, www.worldometers.info. The explanatory variables in this study are Fossil CO_2 emissions per capita, Change in population, Energy intensity level of primary energy, GDP per capita, Carbon dioxide (CO_2) emissions (total).

The dynamic change of all indicators presented in the table 1 in the period 2000–2021 is depicted in the following Figure 1.

From the analysis of Figure 1, it is clear that the variables under study are suitable for analysis. Figure 1 shows clear, consistent, and

Table 4: Selection order criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−229.9674	NA	14.93479	22.56833	22.91650	22.64389
1	−64.02301	205.4550*	0.000288*	11.43076*	14.21616*	12.03526*

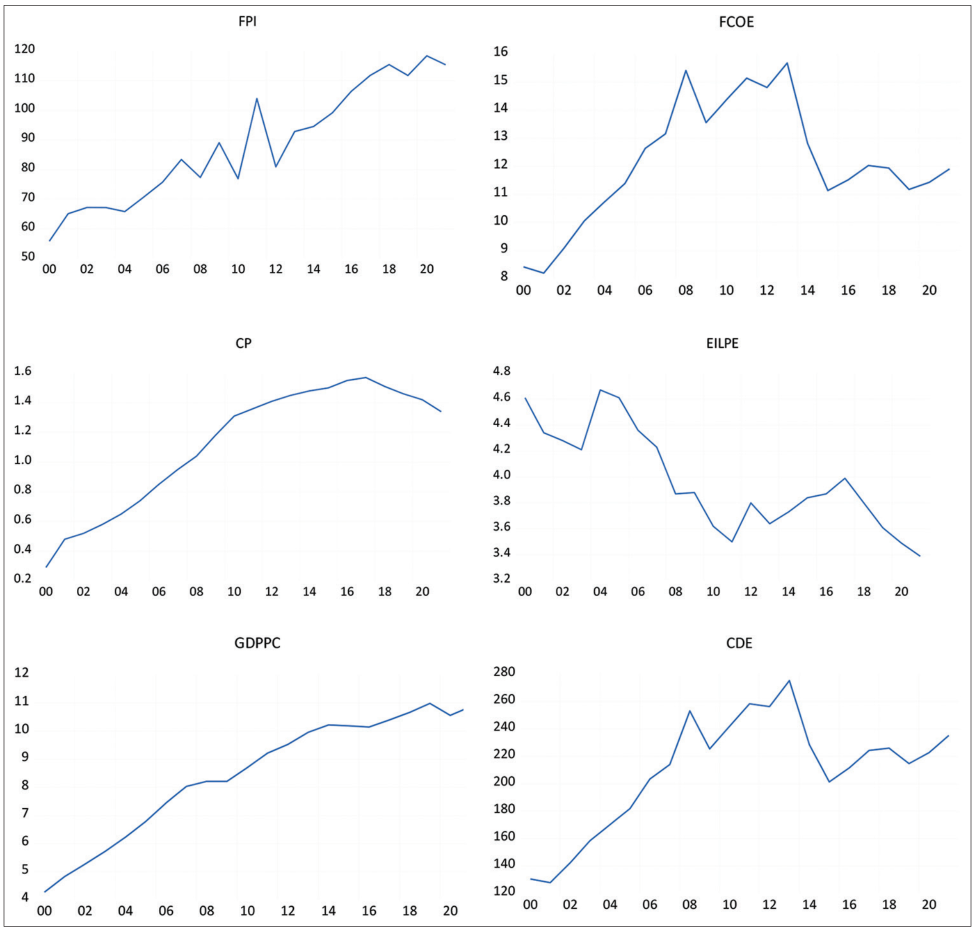
stable time patterns, indicating changes in variables are suitable for further study.

4.2. Descriptive Statistics

This study used descriptive statistics, correlation matrix, and ARDL model to test the hypothesis. Descriptive statistics provide insight into various aspects of a data set. The descriptive statistics results presented in Table 5 show the pooled mean, i.e., mean and median, and the measures of spread and variation such as standard deviation minimum, maximum, skewness and Jarque-Bera statistic for each variable used in our model.

According to descriptive statistics, for FPI, the mean is 88.3777, median is 86.2050, and standard deviation is 19.4964, indicating relatively stable values. The value of the Jarque-Bera statistic is 1.6344, the probability of tie is 0.4417, which is >0.05, so it can be concluded that the series is uniformly distributed. The median of FCOE is 11.9250 and the standard deviation is 2.1438. The standard deviation for all other indicators also exceeds 0.10. The Jarque-Bera statistic of 0.4484 is close to the probability of 7991, which means that the hypothesis of zero normal distribution of FCOE is confirmed at the 10% significance level. In Table 5 we see that for the FPI, FCOE, EILPE indicators, the asymmetry coefficient of the time series is >0, that is, they have right

Figure 1: Evolution of all variables for Kazakhstan (2000-2021)



Source: Authors

Table 5: Values of descriptive statistics of the displayed series

Values	FPI	FCOE	CP	EILPE	GDPPC	CDE
Mean	88.3777	12.1200	1.1200	3.97000	8.4783	209.2305
Median	86.2050	11.9250	1.3250	3.8700	8.96400	218.6830
Maximum	118.3300	15.6800	1.5700	4.6700	10.9900	275.2521
Minimum	55.8400	8.2000	0.2900	3.3900	4.26900	127.7442
Std. Dev.	19.4964	2.1438	0.4130	0.3860	2.1369	41.5807
Skewness	0.09234	88.3777	−0.6239	0.4024	−0.5918	−0.5908
Kurtosis	1.67754	2.3063	1.9145	2.0198	2.03782	2.4630
Jarque-Bera	1.6344	0.4484	2.5075	1.4745	2.1330	1.544015
Probability	0.4417	0.7991	0.2854	0.4784	0.3442	0.4621
Sum	1944.310	266.640	24.6400	87.3400	186.5220	4603.070
Sum Sq. Dev.	7982.304	96.5152	3.58140	3.12900	95.88914	36308.12
Obs	22	22	22	22	22	22

asymmetry. The value of excess for all indicators shows that the distribution is almost normal, without excessive excess.

4.3. Unit Root Test

Before examining the long-term relationships between the series, it is necessary to determine whether they are stationary. Augmented Dickey-Fuller (ADF) unit root tests were used to test the levels or differences of time series variables for stationarity. Some variables can be used at the I(0) level, while other variables should be stationary at the first difference I(1).

As shown in Table 6, the ADF results show that many of the study series are not stationary at the level Level. However, only in the case of 1st difference without Intercept and trend, the variables, including CP, are stationary at the first difference. Thus, the ARDL cointegration methodology is the best method to estimate or test the long-run relationship between the study variables.

The unit root results are consistent with the main assumptions that require the use of the ARDL model test to confirm the existence of long-run relationships between the Kazakh Food Production Index (FDI) and the significant explanatory factors proposed in the study.

4.4. Granger Causality Test

In order to enhance the robustness check rigor, pairwise Granger causality analysis was also used in this study to determine the causal relationships between the variables (Table 2).

To examine the causal relationship between selected variables and the level of FPI, a Granger test is used to test the null hypothesis that changes in the dependent variable are not causal (Noncausality).

The study revealed a cause-and-effect relationship from FCOE, CP, EILPE, GDPPC, CDE to FPI.

4.5. Co-Integration Test

The procedure of testing ARDL boundaries is used in this research to study long-term relationship between FCOE, CP, EILPE, GDPPC, CDE and FPI in Kazakhstan. To investigate the long-term relationship of variables with, ARDL was chosen using a small sample size. Before the co-integration test can be performed, it is important to determine the criteria of the length of the lag. The delay length criterion is determined based on LR, FPE, AIC, SC and HQ. Table 4 shows the results of the selected lag. As shown in Table 3, the chosen length of the beam is 1 because it has more stars and was used throughout the study.

4.6. Results of Long- and Short Run Relationship

In the study using logarithms and first difference from ADF test results, the nonlinear NARDL (equation 2) and linear ARDL (equation 3) models were evaluated, respectively, and for long-term and short-term analysis of the relationship between variables, the results are presented in Table 3 below. The results of the F-cointegration test for all 2 models (Table 3) indicate that the F-statistics obtained (respectively 15.94604 and 5.2363) exceeds the upper limit of 4.84 and is statistically significant at a level of 1-10% of significance. Results show that the selected variables are co-integrated and in the case of Kazakhstan, a long-term relationship between variables is found.

Table 6: ADF unit root tests

Variables	Intercept			Trend and intercept			None		
	Level	First diff.	Order of Integration	Level	First diff.	Order of Integration	Level	First diff.	Order of Integration
FPI	−0.374 (0.896)	−12.4*** (0.000)	I (1)	−7.25*** (0.000)	−12.076*** (0.000)	I (0)	3.151 (0.999)	−9.617*** (0.000)	I (1)
FCOE	−1.926 (0.315)	−4.23*** (0.004)	I (1)	−1.471 (0.807)	−4.743*** (0.006)	I (1)	0.331 (0.772)	−4.242*** (0.000)	I (1)
CP	−1.759 (0.387)	−1.785 (0.376)	>I (1)	1.785 (0.100)	−1.496 (0.793)	>I (1)	−1.657* (0.091)	−2.319** (0.023)	I (0)
EILPE	−1.314 (0.603)	−4.414** (0.003)	I (1)	−2.428 (0.355)	−4.281** (0.015)	I (1)	−0.485 (0.125)	−4.288*** (0.000)	I (1)
GDPPC	−3.479** (0.019)	−3.113** (0.042)	I (0)	−0.711 (0.959)	−5.016*** (0.006)	I (1)	1.257 (0.964)	−1.964** (0.049)	I (1)
CDE	−1.941 (0.308)	−4.35*** (0.003)	I (1)	−1.539 (0.782)	−4.668*** (0.007)	I (1)	−0.785 (0.875)	−4.153*** (0.000)	I (1)

*, **, *** denote statistically significant at the 10%, 5% and 1% levels, respectively
P-value is inside brackets

Given that the selected variables are co-integrated in the long term, we can move on to the next stage which requires estimation of the long and short-term coefficients. Considering the logarithmic estimation of model 1 -NARDL for both long and short periods, it is possible to estimate the impact of shock on 1% of explaining variables on dependent variable. Model 2 - ARDL was estimated using first order, we can estimate how the change of 1 unit of explanatory variables affects dependent variable in both long-term and short-term periods.

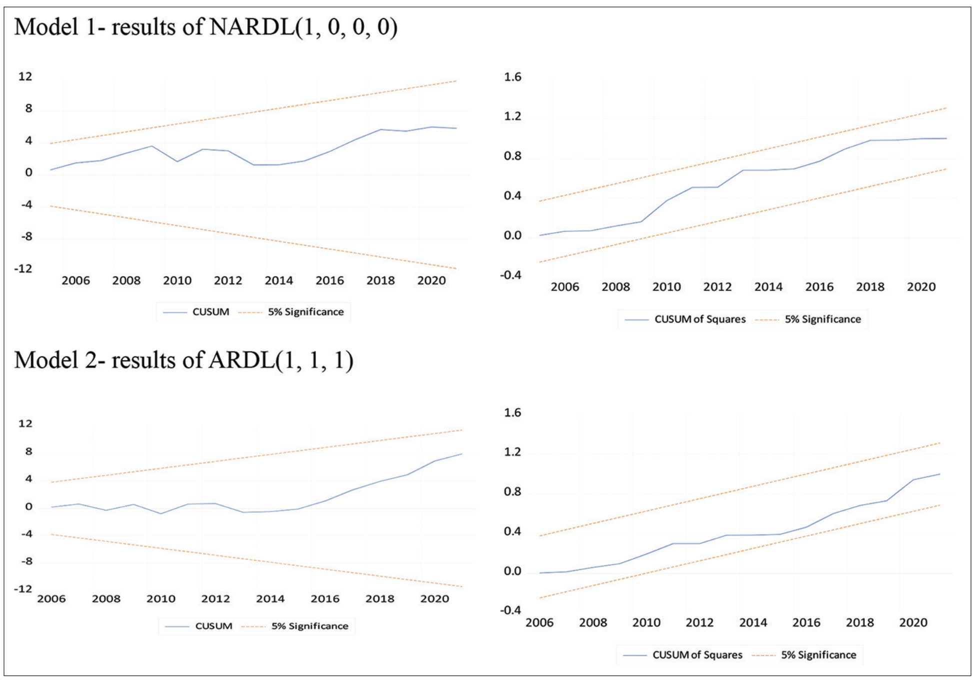
Table 7 shows the results of diagnostic studies. LM statistic is 0.0690, P = 0.7961. As a result, we accept the null hypothesis in this analysis and conclude that there is no serial correlation in the model. Heteroscedasticity tests revealed an F-statistic of 1.5240 and a probability of 0.2428, both exceeding the 0.05% significance level, indicating that the model was homoscedastic. The model accepts the null hypothesis of the normality test and concludes that the residuals are normally distributed, as evidenced by an F-statistic of 1.7965and a P = 0.4073, both of which have a significance level >5%. Finally, all diagnostic tests for Langrage multiplier serial correlation test, Jarque-Bera normality test, and heteroscedasticity test were successful, indicating the stability of the NARDL1 model. ARDL2 model stability is also explained accordingly.

4.7. Stability Tests

The CUSUM and CUSUM Squares tests are used to test whether the estimated models' coefficients remain constant over time, which is an indicator of model stability.

The results of the CUSUM and CUSUMSQ stability tests are shown in Figure 2. At 5% importance, the blue line not crossing

Figure 2: CUSUM and CUSUM squares tests



Source: Authors

Table 7: Results of NARDL and ARDL Estimation (2000-2022)

Model 1- results of NARDL (1, 0, 0, 0) estimationΔLOG (FPI)			Model 2- results of ARDL (1, 1, 1) estimationΔFPI		
Variable	**Coefficient**	**t-Statistic (Prob.)**	**Variable**	**Coefficient**	**t-Statistic (Prob.)**
Short Run					
LOG (FPI(−1))	−1.4603	−7.4420 (0.000)***	FPI(−1)*	−0.858071	−3.7433 (0.002)**
LOG (FCOE)	0.4327	−6.9149 (0.000)***	CP(−1)	34.35829	3.4559 (0.003)**
LOG (GDPPC)	1.3455	5.4721 (0.000)***	EILPE(−1)	10.62848	3.2908 (0.004)**
LOG (CDE)	−1.4603	7.4538 (0.000)***	D (CP)	−72.34553	−1.7474 (0.099)*
			D (EILPE)	−8.931834	−0.9842 (0.340)
Long Run					
LOG (FCOE)	−1.4603	−14.831 (0.000)***	CP	40.04134	7.719 (0.000)***
LOG (GDPPC)	0.4327	9.2624 (0.000)***	EILPE	12.38649	6.68 (0.000)***
LOG (CDE)	1.3455	26.8275 (0.000)***			
Diagnostic	**F-statistics**	**P-value**	**Diagnostic**	**F-statistics**	**P-value**
Serial correlation	0.0690	0.7961	Serial correlation	0.9442	0.4161
Heteroskedasticity	1.5240	0.2428	Heteroskedasticity	1.2520	0.3443
Jarque-Bera	1.7965	0.4073	Jarque-Bera	0.2962	0.8624

Coefficients are statistically significant at ***1%, **5%, *10% level of significance.
Compiled by the authors

the red lines indicates the stability of the model. These tests are also used to study the long-term dynamics of the regression.

5. CONCLUSION

In this research, authors studied relationship between Food Production index and Fossil CO_2 emissions per capita, Change in population, Energy intensity level of primary energy, GDP per capita and Carbon dioxide (CO_2 emissions (total) in the Republic of Kazakhstan for the period 2000–2021 and aimed to prove HO-H3 hypothesis from Literature Review.

According to the results of Model 1 NARDL (1, 0, 0, 0) model, in this study based on short-term estimates, it can be concluded that FCOE, GDPPC are one of the determining factors among the selected variables that have a positive impact on Food production index in other words, a 1% increase in FCOE increases FPI by 0.43% at a 1% significance level, and a 1% increase in GDPPC increases FPI by 1.35% at a 1% significance level. Another interesting result is that a 1% decrease in CDE generally decreases Food production index by 1.46%. Long-term estimates also show that GDPPC and CDE have a positive impact on the Food production index with elasticities of 0.43 and 1.35, respectively. This highlights the impact of growth in Carbon dioxide (CO_2) emissions (total) and GDP per capita ($) on the Food production index. Thus, hypotheses H_1 and H_2 were proven.

Model 2 ARDL showed that in the short term, the change in CP can have a negative impact on the Food production index. CP in the long term is positively correlated with FPI. Energy intensity level of primary energy (EILPE) has a negative impact on the Food production index in the short term, and in the long term it has a positive effect with a coefficient of 12.38649, according to model 2. Thus, hypothesis H_0 has been proven. EILPE does not affect FPI in Kazakhstan. At the same time, it was confirmed that the Food production index level in period t depends on its value in period t-1. This negative impact of the variable lag on the Food production index is also confirmed in the other two models. Therefore, hypothesis H_3 was proven in the short term.

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