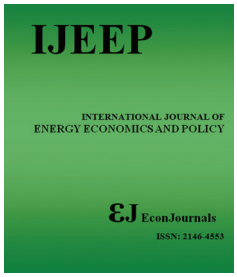

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Determinants of Nuclear Energy Consumption in South Asia: Economic and Energy Security Issues

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ABSTRACT

The objective of the study is to examine the causal relationship between: (i) Nuclear energy consumption (*NEC*) and economic determinants (i.e. labor force, gross fixed capital formation and gross domestic product per capita (*GDPPC*), and (ii) nuclear consumption and energy security (*ES*) issues (i.e. technology infrastructure [*TIF*], energy sources, conditions of land, concern of *ES* and political stability in the context of South Asia. The study brings an annual aggregate data for South Asia from the period of 1960 to 2012. The autoregressive distributed lag bounds testing approach employed for investigating the short- and long-run relationship between the variables, while modified version of the Granger causality used for determining the causal relationship among *NEC*, economic factors and *ES* issues. The results show that there is a long-run relationship between *NEC*, economic indicators and *ES* issue; however, the "*a priori"* expectations of the variables differ with the *NEC*. The results of causality test validate the neutrality hypothesis between, (i) *NEC* and labor force; (ii) *NEC* and conditions of land; and (iii) nuclear energy and *GDPPC*. Further, the causality test validates the feedback hypothesis between (i) Nuclear energy and *TIF*; and (ii) nuclear energy and energy sources in the region. The results indicate the unidirectional causality running from nuclear energy to gross capital formation but not vice versa. Similarly, *ES* Granger cause nuclear energy which indicates that *ES* has a vital role to increase nuclear energy in the region.

Keywords: Nuclear Energy Consumption, Economic Growth, Energy Security, South Asia
JEL Classifications: C32, Q43

1. INTRODUCTION

The Asian energy trends are the most visible global interest, with profound inferences for the world economy and geopolitics (Hong and Lugg, 2014). Asian economies are highly reliant on imported oil and gas to fuel economic growth. However, the ecological challenges related to greenhouse gas (GHG) emissions, human precautions and rising energy costs affected Asian governments to use the conventional hydrocarbon energy resources. In the interim, Russia and the central Asian states have a momentous proportion of the World's primary energy resources and are appearing for ways to amplify such exports to enlarge and branch out into new markets in Asia and Europe (ISDP, 2013). Nuclear power is one of the few viable sources of energy that is nearly free of GHG emissions. The importance of nuclear energy consumption (*NEC*) for climate mitigation has been emerged during the unfortunate nuclear accident in Fukushima, Japan in 2011 (Kim et al., 2014). Brown and Kaplow (2014) conclude that the nuclear support is a significant determinant of whether states practices nuclear armaments from the rest of the world. In the similar lines, Park and Ohm (2014) examine the public perceptions of the Fukushima accident in the South Korea. The study found interesting evidences which include the distinguished variations of public perceptions i.e., public feelings, apparent gains, confidence, intention to use, acquaintance and risks between before and after the underground eruption. Stern (2014) emphasized on the role of the energy science and social research for integrating human-energy to formulate sustainable policies for the developing countries. Shafiei and Salim (2014) investigate the determinants of carbon dioxide emissions in OECD countries, over a period of 1980-2011. The results reveal that there is a significant and positive relationship between non-renewable energy and carbon emissions, whereas renewable energy consumption decreases carbon dioxide emissions in the region.

Evans and Mangelsdorf (2014) presented the individual viewpoint on nuclear receptors and investigated the integration and

coordination signaling networks. The study concludes that there is a need of multicellular life which associated with the ligands and transcriptional mechanism for integrating signaling networks. Galvin (2014) examine the changes in energy effectiveness and energy consumption in each of the 28 European Union countries including Norway, for the years 2000-2011. The results show that in majority of the European Union countries, the rebound results are in the range of 0-50% but newer lands show 100-552%. Meade and Islam (2014) examine the usage of renewable energy technologies (RET) in 14 European countries in a multi-country growth curve framework. The results confirm the neutrality hypothesis between the price of fossil fuels and changes in the growth of RET usage over time. Akhmat et al. (2014) focused on the hypothesis related with the energy led environmental degradation in the selected SAARC countries, covering the period of 1975-2011. The results confirm the energy led environmental degradation hypothesis in SAARC countries. Nässén (2014) examine the long-run relationship between private consumption, energy consumption and GHG emissions from Swedish households between the years 1993 and 2006. The results show that the total private expenditures is the major factor of households' energy use and GHG emissions with expenditure elasticities of 0.77 and 0.85 respectively. Siegrist et al. (2014) conducted the survey of 561 respondents of German and French speaking regions of Switzerland regarding the post affects of the Fukushima accident. The results show that the people professed somewhat more hazards related to the nuclear power after the misfortune in Fukushima. Aguilera (2014) examine the market shares of gases, liquids and solids in the Asia Pacific from 1850 to 2010. The Asia Pacific is found to have enormous natural gas resources, though suitable policies are needed to develop the potential. Ozturk and Bilgili (2015) examined the relationship between biomass energy consumption and economic growth in the panel of Sub-Saharan African countries, over the period of 1980-2009. The results show that biomass energy consumption has a significant impact on African's growth. In the similar line, Bilgili and Ozturk (2015) examined biomass energy consumption and economic growth in the panel of G-7 countries and found that biomass energy have a positive impact on G-7 countries economic growth. Shahbaz et al. (2015) investigated the environmental Kuznet curve in the context of Portugal and confirmed the visibility of environmental Kuznet curve both in the short- and long-run. Isa et al. (2015) surveyed the causal relationship between energy consumption and economic growth studies and highlighted the importance of causal relationship between the variables across the countries.

In the light of above discussion, the present study examines the causality relationship between *NEC*, economic indicators and energy security (*ES*) issues, by using the aggregate data of South Asia, during 1960-2012.

2. DATA SOURCE AND METHODOLOGICAL FRAMEWORK

The study is based on annual data of *NEC*, gross domestic product per capita (*GDPPC*), total labor force (*LR*); gross fixed capital information (*GFCF*); technology infrastructure (*TIF*); energy sources (*ENRG*); conditions of land (*LAND*); *ES* and political stability (*PS*) covering a time period from 1960 to 2012 in South Asia. Aggregate data is taken from World Bank (2013) to avoid the individual countries shocks. *NEC* is expressed in terms of percentage of total energy use. The *GDPPC* is expressed in constant 2000 US dollars, labor force in terms of total labor force; *GFCF* in terms of percentage of GDP; *TIF* in million US $; *ENRG* in US $ million; *LAND* is in total arable land per hectare; *ES* in US $ million and *PS* is the dummy variable i.e. 0 expressed *PS* while 1 expressed political instability in the regions.

2.1. Econometric Framework

The study adopted the following sequential steps for evaluating nuclear energy issues both economic and security concerns in South Asia i.e.,

Step 1: Unit root test is used for analyzing stationary properties in the variables.

Step 2: For analyzing long-run relationship between the variables, the study used Wald *F*-statistics for upper bound critical values as suggested by Pesaran et al. (2001) and Narayan (2005).

Step 3: To estimate short-and long-run elasticities by using autoregressive distributed lag (ARDL) technique.

Step 4: To examine the causal relationship among the variables, the study employed Wald *F*-statistics with imposing restrictions in the multivariate framework.

There are a number of possible rationales for using the ARDL econometric technique (sometimes called "bounds testing approach" suggested by Pesaran et al., 2001) i.e., however, the two most significant validations are:

- In unit root estimation, if there have a mixture of order of integration between the variables, then Johansen's cointegration in multivariate framework may not suitable for further estimation. There would be the good justification by using ARDL technique for those modeling, as it incorporates both zero and one order of integration in their framework
- There is not a significant requirement of large data set for estimations, as this technique is suitable for small or finite sample size as well.

The following equation has been estimated in the unrestricted error correction model (ECM) i.e.,

$$\begin{aligned}\Delta \ln(NEC)_t &= \beta_0 + \beta_1 \ln(NEC)_{t-1} + \beta_2 \ln(GDPPC)_{t-1} \\ &+\beta_3 \ln(GCFC)_{t-1} + \beta_4 \ln(LF)_{t-1} + \beta_5 \ln(TIF)_{t-1} \\ &+\beta_6 \ln(ENRG)_{t-1} + \beta_7 \ln(LAND)_{t-1} + \beta_8 \ln(ES)_{t-1} \\ &+\beta_9 (PS) + \sum_{i=1}^{p} \beta_{10} \Delta \ln(NEC)_{t-i} + \sum_{i=0}^{q} \beta_{11} \Delta \ln(GDPPC)_{t-i} \\ &+\sum_{i=0}^{r} \beta_{12} \Delta \ln(GCFC)_{t-i} + \sum_{i=0}^{s} \beta_{13} \Delta \ln(LF)_{t-i} + \sum_{i=0}^{s} \beta_{14} \Delta \ln(TIF)_{t-i} \\ &+\sum_{i=0}^{s} \beta_{15} \Delta \ln(ENRG)_{t-i} + \sum_{i=0}^{s} \beta_{16} \Delta \ln(LAND)_{t-i} \\ &+\sum_{i=0}^{s} \beta_{17} \Delta \ln(ES)_{t-i} + \sum_{i=0}^{s} \beta_{18} \Delta PS + u_t \end{aligned} \quad (1)$$

Where Δ is the first-difference operator and u_t is a white-noise disturbance term. Equation (3) also can be viewed as an ARDL of order (*p*, *q*, *r, s*). Equation (3) indicates that *NEC* tends to be influenced and explained by its past values. The Wald test can be carry out by imposing restrictions on the estimated long-run coefficients of *NEC* and its determinants.

The null and alternative hypotheses are as follows:

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = 0$ (no long-run relationship)

Against the alternative hypothesis

H_a: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq 0$ (A long-run relationship exists)

To establish the causality direction, we estimate the following vector ECM (VECM) i.e.,

$$\begin{bmatrix} \Delta \ln NEC_t \\ \Delta \ln GDPPC_t \\ \Delta \ln GFCF_t \\ \Delta \ln LF_t \\ \Delta \ln TIF_t \\ \Delta \ln ENRG_t \\ \Delta \ln LAND_t \\ \Delta \ln ES_t \\ \Delta PS_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \\ \alpha_7 \\ \alpha_8 \\ \alpha_9 \end{bmatrix} + \begin{bmatrix} A_{11i} \ldots A_{12i} \ldots A_{13i} \ldots A_{14i} \\ A_{21i} \ldots A_{22i} \ldots A_{23i} \ldots A_{24i} \\ A_{31i} \ldots A_{32i} \ldots A_{33i} \ldots A_{34i} \\ A_{41i} \ldots A_{42i} \ldots A_{43i} \ldots A_{44i} \\ A_{51i} \ldots\ldots A_{54i} \\ A_{61i} \ldots\ldots A_{64i} \\ A_{71i} \ldots\ldots A_{74i} \\ A_{81i} \ldots\ldots A_{84i} \\ A_{91i} \ldots\ldots A_{94i} \end{bmatrix} \times \begin{bmatrix} \Delta \ln NEC_{t-i} \\ \Delta \ln GDPPC_{t-i} \\ \Delta \ln GFCF_{t-i} \\ \Delta \ln LF_{t-i} \\ \Delta \ln TIF_{t-i} \\ \Delta \ln ENRG_{t-i} \\ \Delta \ln LAND_{t-i} \\ \Delta \ln ES_{t-i} \\ \Delta PS \end{bmatrix} + \begin{bmatrix} \delta \\ \gamma \\ \lambda \\ \varphi \\ \lambda \\ \pi \\ \zeta \\ \psi \\ \omega \end{bmatrix} \times [ECT_{t-1}] + \begin{bmatrix} \xi_{1t} \\ \xi_{2t} \\ \xi_{3t} \\ \xi_{4t} \\ \xi_{5t} \\ \xi_{6t} \\ \xi_{7t} \\ \xi_{8t} \\ \xi_{9t} \end{bmatrix} \quad (2)$$

The residuals $\xi_{1t}, \xi_{2t}, \xi_{3t}$ and ξ_{4t} are stationary and spherical distribution. ECT_{t-1} is the lagged error-correction term derived from the cointegrating equation.

3. RESULTS AND DISCUSSION

The study employed augmented dickey-fuller (ADF) unit root tests for examine the stationary properties of the candidate variables. The results are presented in Table 1.

The results confirmed the unit root problem, as *NEC*, economic factors and *ES* shows non-stationary series at level, however, taking first difference, the variables become stationary. The results considered that the candidate variables having an order of integration one i.e. we said I(1) variables. In next step, the study used Hendry's general-to-specific modeling approach with maximum lag order of three for the conditional ARDL-VECM. Table 2 presented the results of bounds test with Wald *F*-statistics in ARDL-ordinary least squares regressions. The results show that each model specification in the table is significant at 1% level. Thus, the model contains long-run cointegration relationships between the variables.

The result of Table 2 implies that both economic and *ES* variables are moving together with *NEC* in the long-run, though divergences may take place in the short-run. Additionally, the existence of cointegration means that the explanatory variables are rightly considered. Table 3 shows the long-run coefficients derived from ARDL model.

Table 1: ADF unit root test

Variables	Level	First difference	
	Constant	Constant	Constant and trend
NEC	I (0)	I (1)	I (1)
RGDPPC	I (0)	I (1)	I (1)
LR	I (0)	I (1)	I (1)
GFCF	I (0)	I (1)	I (1)
TIF	I (0)	I (1)	I (1)
ENRG	I (0)	I (0)	I (1)
LAND	I (0)	I (1)	I (1)
ES	I (0)	I (1)	I (1)

I (0) indicates non-stationary series at level, while I (1) indicates after taking first difference, the series would become stationary. For this purpose, McKinnon (1996) critical values are used for benchmark. Schwarz information criteria is selected for optimal lag length selection which ranges from 0 lag to lag 1, ADF: Augmented dickey-fuller, NEC: Nuclear energy consumption, LR: Labor force, GFCF: Gross fixed capital information, TIF: Technology infrastructure, ES: Energy security

Table 2: Results of bounds test

Dependent variable	Wald *F*-statistics	Outcome
F_{NEC} (LNECILGDPPC, LGFCF, LLR, LTIF, LENRG, LLAND, LES)	1702.29*	Co integration
FG_{DPPC} (*LGDPPCILNEC, LGFCF, LLR, LTIF, LENRG, LLAND, LES*)	93.51*	Co integration
F_{GFCF} (*LGFCFILGDPPC, LNEC, LLR, LTIF, LENRG, LLAND, LES*)	94.21*	Co integration
F_{LR} (*LLRILGDPPC, LGFCF, LNEC, LTIF, LENRG, LLAND, LES*)	6.97*	Co integration
F_{TIF} (*TIFILGDPPC, LGFCF, LNEC, LLR, LENRG, LLAND, LES*)	14.28*	Co integration
F_{ENRG} (*LENRGILGDPPC, LGFCF, LNEC, LLR, LTIF, LLAND, LES*)	16.96*	Co integration
F_{LAND} (*LLANDILGDPPC, LGFCF, LNEC, LLR, LTIF, LENRG, LES*)	6.69*	Co integration
F_{ES} (*LESILGDPPC, LGFCF, LNEC, LLR, LTIF, LENRG, LLAND*)	27.25*	Co integration

Critical value (%)	Pesaran et al. (2001)		Narayan (2005)	
	Lower bound value	Upper bound value	Lower bound value	Upper bound value
1	4.29	5.61	4.614	5.966
5	3.23	4.35	3.272	4.306
10	2.72	3.77	2.676	3.586

*Significance at 1% level, NEC: Nuclear energy consumption, LR: Labor force, GFCF: Gross fixed capital information, TIF: Technology infrastructure, ES: Energy security

The results indicate that in the long-run, both *GDPPC* and gross capital formation has a significant relationship with the *NEC*, as if there is 1% increase in *GDPPC* and gross capital formation, nuclear energy increases by 0.244% and 0.625% respectively. The results imply that deployment of the nuclear plants increase the gross capital formation and the *NEC*. On the other hand, *TIF*, energy sources and *PS* significantly and positively associated with the *NEC* in South Asia. The significance and positive association of *PS* dummy indicated that along with increase *PS*, South Asia emerged as a nuclear energy intensive region in the World. Table 4 shows the short-run dynamic coefficients managed from the ECM Equation (4).

Table 3: The estimated long-run elasticities using the ADRL approach dependent variable: ΔLn $(NEC)_t$

Variable	Coefficient	*t*-statistic	*P*
Constant	−0.028	−0.096	0.923
Ln $(GDPPC)_{t-1}$	0.244	2.043	0.049
Ln $(GFCF)_{t-1}$	0.625	2.625	0.038
Ln $(LR)_{t-1}$	0.013	0.831	0.411
Ln $(TIF)_{t-1}$	0.121	2.102	0.052
Ln $(ENRG)_{t-1}$	0.412	5.121	0.000
Ln $(LAND)_{t-1}$	0.023	1.712	0.113
Ln $(ES)_{t-1}$	0.161	1.625	0.102
PS	0.552	4.252	0.001

Model criteria/goodness of fit: R^2=0.625; Adjusted R^2=0.612; *F*-statistics=6.895 [0.000], Durbin-Watson=1.919, Diagnostic checking: Jarque-Bera normality test=1.425 [0.602]; LM Breusch-Godfrey serial correlation=0.988 [0.383]; White heteroscedisticity=0.4603 [0.887]; Ramsey reset specification error test=0.247 [0.622]. In diagnostic checking, the probability values are in the square bracket. GFCF: Gross fixed capital information, TIF: Technology infrastructure, ES: Energy security, NEC: Nuclear energy consumption, LR: Labor force, GFCF: Gross fixed capital information, GDPPC: Gross domestic product per capita, PS: Political stability

Table 4: Estimated short-run elasticities using the ADRL approach dependent variable: Ln (*NEC*)t

Variable	Coefficient	*t*-statistic	*P*
Constant	−0.227	−1.031	0.3100
Ln $(GDPPC)_{t-1}$	1.085	2.099	0.043
Ln $(GFCF)_{t-1}$	−0.098	−0.307	0.760
Ln $(LR)_{t-1}$	0.017	1.759	0.088
Ln $(TIF)_{t-1}$	1.052	6.258	0.000
Ln $(ENRG)_{t-1}$	0.385	2.458	0.035
Ln $(LAND)_{t-1}$	0.195	1.596	0.124
Ln $(ES)_{t-1}$	0.259	2.001	0.078
PS	−0.254	−2.669	0.025
MA (1)	−0.952	−53.739	0.000
ECT_{t-1}	−0.252	−2.493	0.031

Model criteria/goodness of fit: R^2=0.668; Adjusted R^2=0.625, Diagnostic checking: JB=1.902 [0.386]; LM-1=0.752 [0.480]; white heteroscedisticity=0.994 [0.492]; The ECT_{t-1} is the one period lagged error-correction term. Probability values are quoted in square brackets. GFCF: Gross fixed capital information, TIF: Technology infrastructure, ES: Energy security, ECT: Error correction model, PS: Political stability

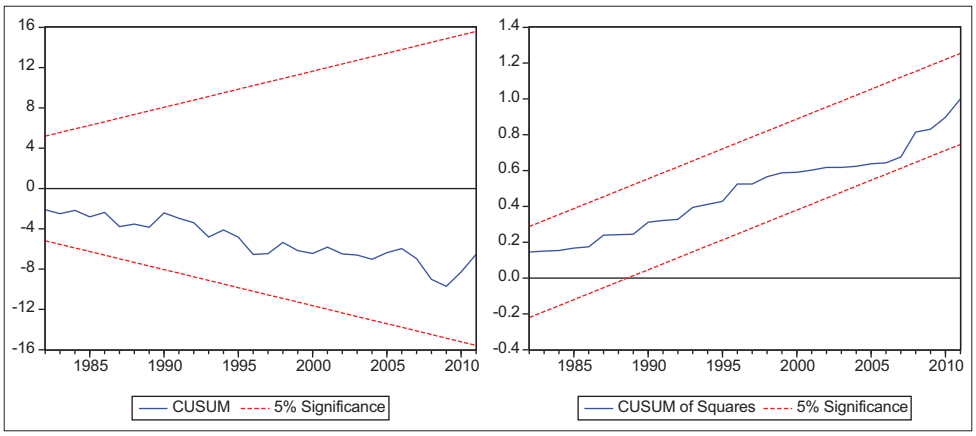
The results in the short-run reveal that explanatory variables i.e., *GDPPC* and *LR* are positively related to *NEC* which is statistically significant at 1%, 5% and 10% respectively. The short-run effect of *GDPPC* and *LR* on *NEC*, contributing to about 1.085% and 0.017% in South Asia. *ES* variables i.e., *TIF*, energy sources; *ES* and *PS* have a significant impact on nuclear energy, however, the magnitude varies with the *NEC* i.e. *TIF* has one-to-one corresponding relationship with the nuclear energy, while there has been less elastic relation with the energy sources and *ES*. *PS* shows that there is negative relationship with the *NEC* which shows that along with increase in political instability nuclear energy decrease by 0.254%. The error correction coefficient $(ECT)_{t-1}$, estimated at −0.252 is statistically significant at 5%, this shows that about 25.2% of disequilibria from the previous year's shock converge back to the long-run equilibrium in the

Table 5: Short-run causality test (Wald test *F*-statistic)

Variables	Causality directions	Decision
NEC and *GDPPC*	≠	*NEC* and *GDPPC* holds neutrality hypothesis
NEC and *GFCF*	→	*NEC* Granger cause *GFCF* i.e., unidirectional causality between them
NEC and *LR*	≠	*NEC* and *LR* holds neutrality hypothesis
NEC and *TIF*	⇔	Feedback hypothesis between the variables
NEC and *ENRG*	⇔	Feedback hypothesis between the variables
NEC and *LAND*	≠	*NEC* and *LAND* holds neutrality hypothesis
NEC and *ES*	←	*ES* Granger cause *NEC* i.e., unidirectional causality between them

⇔: Show bidirectional, →: Unidirectional conservation hypothesis, ←: Unidirectional growth hypothesis, and ≠: No causality, NEC: Nuclear energy consumption, LR: Labor force, TIF: Technology infrastructure, GDPPC: Gross domestic product per capita, RNRG: Energy sources

Figure 1: Stability statistics



current year. The value of R^2 and adjusted R^2, is 0.668 and 0.625 respectively. The study advances the stability tests by using CUSUM and CUSUM of squares tests in Figure 1.

Figure 1 indicates that the estimated parameters are stable and significant at 5% level, over the sample period of 1960-2012. The dynamic short-run causality presented in Table 5.

The results show that there is bidirectional causality between *NEC* and *TIF*; and between *NEC* and energy sources in South Asia. While, causality running towards *NEC* to *GFCF* but not vice versa which implies that there is unidirectional causality exist between them. *ES* Granger cause *NEC* but not vice versa, which implies energy sources cause *NEC* but not another route. Finally, there is no causality between *NEC* and *LR*; *NEC* and *GDPPC* and *NEC* and *LAND* which holds neutrality hypothesis between them. Lecamwasam and Uyangoda (2013) show their concern on South Asian nuclear capabilities and their security issues. Economic growth and growing populations have put South Asia's *ES* in a dangerous state. Both energy and power shortages are exploiting development in some of the region's least developed locations driving political insurgences and social disruption (Brookings, 2011).

4. CONCLUSION

The objective of the study is to examine the role of economic variables and security issues on *NEC* in the South Asia, which are the ongoing debate in this region. The results reveal that both economic and *ES* issues played a vital role to analyze *NEC* in the region, however, the magnitude of influencing nuclear energy more pronounced *ES* issues rather than economic issues. The following conclusion has been emerged with this exercise i.e.,

- ADF unit root test confirmed the existence of unit root problem in nuclear energy, *ES* issues and economic variables, thus there is a need to adopt sustained economic and *ES* policies for averting wide variations in the data set of the candidate variables over a period of time
- The study evaluated eight different models and each model shows the cointegration relationship between the variables
- The short-run elasticities suggest that there is one-to-one corresponding relationship between (i) GDP and *NEC* and between, (ii) *TIF* and *NEC* in the South Asia
- The total labor force, *ES*, *PS*, and energy sources have a less elastic relationship with the *NEC* in the short-run
- In the long-run, these results has been evaporated in terms of less magnitude and different signs, as GDP, gross capital formation, *TIF*, energy sources and *PS* have a less elastic relationship with the *NEC* in the region
- The dummy variable of *PS* shows the positive association with the *NEC* which indicates that the South Asia come forwarded as a nuclear intensive region in the world
- The results of Granger causality indicate the unidirectional, bidirectional and no cause-effect relationship between the variables
- The study confirmed the feedback hypothesis between two most promising *ES* variables in relation with the *NEC* i.e., *TIF* and energy sources in the South Asia, while, *ES* Granger cause *NEC* but not *viz*. The *NEC* Granger cause gross capital formation in the region, but not *viz*.
- Labor force, *GDPPC* and land have no cause effect relationship with the *NEC* which holds neutrality hypothesis between them.

These results indicate the importance of nuclear consumption and *ES* issues in the South Asia. *ES* issues should be adjusted according to the geographic importance of South Asia in the world.

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