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THE CAUSAL LINK BETWEEN ELECTRICITY GENERATION AND CO_2 EMISSIONS: TODA AND YAMAMOTO APPROACH

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Abstract: *The link between energy consumption and CO_2 emissions has received a significant research attention in the last few decades in the case of Turkey. The authors in general agree on the positive link between these two macroeconomic terms. However, the link between electricity generation and CO_2 emissions did not receive much attention what was the motivation to conduct this study. Thus, this paper aims to provide empirical evidence on the link between these two variables while controlling for the role of the population growth. The time-series data are collected at annual basis in the period between 1974 and 2016. Our results reveal a bidirectional causal link between electricity generation and population growth. These findings imply that population growth stimulates the electricity generation. In addition, electricity generation tends to stimulate the population growth. This is since some of the countries in the World have big problems with electricity supply. It influences negatively the manufacturing sector, educational sector as well as many other sectors. Moreover, a bidirectional link between population growth and CO_2 emissions are recorded. More population is expected to demand more working place, and firms especially those in industry sector are known as significant energy gluttons. The empirical evidence of this paper can serve as an important insight for decision makers. At first, it suggests the necessity to think of the possibilities to develop renewable energy in Turkey. This is since Turkey has a great potential in the fields of renewable energy. In this light, Turkey may solve the problem of the great reliance on the imported energy. Moreover, the business climate should be more favorable for investors tending to support the projects in the fields of renewable energy. Apart from these, it is of great importance to make a necessary effort to increase the energy efficiency which will reduce the current energy consumption and CO_2*

emission consequently. At last, it would be necessary to educate both, the private and public sector, on the benefits of renewable energy.

Key words: *CO_2 emissions, electricity generation, Toda and Yamamoto approach, Turkey.*

The JEL classification: *P28, P48, Q56.*

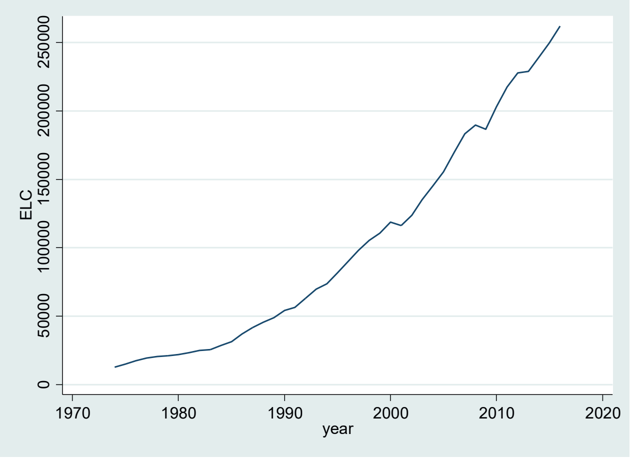
INTRODUCTION

Energy is one of the most important topics nowadays since it is just necessary to operate either daily life activities or some complex business activities. Due to its great importance, it has also brought up a great concern due to the many issues connected with the fossil fuels based energy (Kahouli, 2018). Among these concerns, one of the biggest is environmental. In the line with these issues, it is of key importance to mention the exponential population growth all around the world. As a result, the demand for energy has been rising very fast. On the other hand, it is important to emphasize that in the last few decades the most important energy sources were oil and gas. However, these sources are expected to decrease in the near future due to the limited resources as well as environmental issues.

In parallel with previous paragraphs, it is important to emphasize that electricity is one of the forms of energy that is easiest to control. In addition, the transportation and distribution is easier compared to the other forms of energy. In addition, the production is cleaner and one of the most important properties is efficiency. Due to these properties, electricity is expected to play a great role in the world energy market taking into account the challenges the world faces especially climate change (EIA, 2010). Climate change connected with the environmental pollution caused by fossil fuels based energy sources is the externality of the growth process. CO_2 emissions depend significantly on the population growth and the change of the standard of living. To meet this increasing energy demands, governments will need to invest much effort and financial resources (Siddiqui and Fleten, 2010). This is since government expenditure is recognized as a key source of liquidity (Abul, 2019). As a possible solution, new research and development tends to reduce the pollution and increase the energy efficiency (Tamazian and Rao, 2010).

With regards to Turkey, it has recorded a fast economic growth in the last decades. In addition, the population has grown significantly together with the energy demand. This is why the link between energy consumption and economic growth has been explored quite intensively in the research to date (Nazlioglu, Kayhan, and Adiguzel, 2013; Altinay and Karagol, 2004).

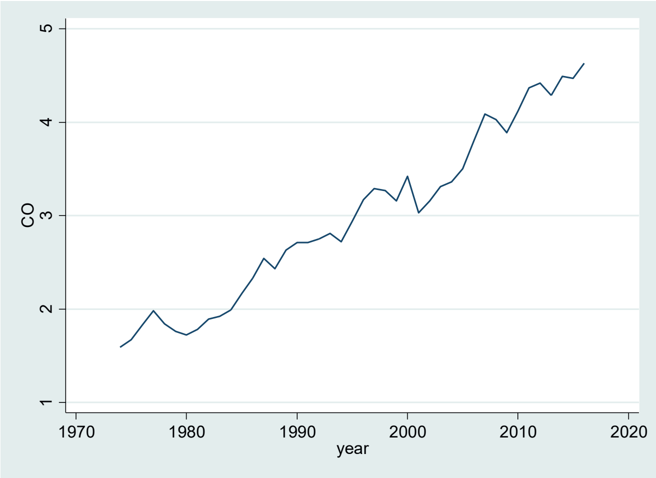
Figure 1. Electricity Generation in Turkey



Source: *Authors*

In addition, the link between electricity consumption and economic growth or electricity consumption and CO_2 emissions has received much attention between the research community (Ghosh, 2002; Yoo, 2005) at the global level as well as in the case of Turkey (Altinay and Karagol, 2005). However, the link between electricity generation and CO_2 emissions has not been explored quite intensively in the research to date. This was the motivation to conduct this research taking into account the fact that Balat (2009) suggests that Turkey highly depends on the imported energy. With regards to the statistics, Figure 1 suggests increasing electricity generation from both renewable and nonrenewable sources. In addition to the exponential increase in the electricity generation, the CO_2 emissions in Turkey have also been rising in the period of interest (Figure 2).

Figure 2. CO_2 Emissions in Turkey



Source: *Authors*

Despite to the fact that both of the economic terms outline significant increase in the recent decades, the link between those did not receive much attention in the case of Turkey. Moreover, just few studies have taken into consideration the role of the population growth. Thus, we have conducted this study to try to fill in this gap in literature. The originality of this paper can be summarized in the two lines. First, from the best of our knowledge this is the first attempt to analyze the link between electricity generation and CO_2 emissions while controlling for the population growth in the case of Turkey. Second, this paper employs Toda and Yamamoto approach to explore this link in order to deal with the different order of integration of the variables.

With regards to the organization of the paper, after the brief introductory remarks we provide summarized literature review on the link between the variables of interest. Furthermore, we proceed to the explanation of the methodology and the variables used to conduct the empirical research. Results section outlines the most important findings together with the interpretation while the paper ends by the concluding remarks section.

LITERATURE REVIEW

The literature review section summarizes the recent empirical evidence on the link between the variables of interest. Cai, Sam, and Chang (2018) have investigated the potential link between the growth of economy, emissions of greenhouse gases and the consumption of clean energy in the case of G7 countries. The findings suggest the cointegration link between the variables of interest for most of the countries in the sample. Thus, the findings give some important insights for decision makers to provide more efficient strategies of energy use in order to reduce the emissions of CO_2 that are found to be a serious concern in G7 countries. These findings are supported by Apergis and Payne (2010). Electricity supply is found to play a very important role.

With regards to the panel data analysis, it is also important to emphasize the study by Cowan, Chang, Lotz, and Gupta (2014) who analyze the nexus of interest in the case of BRICS countries. They have collected the data in the period between 1990 and 2010. The results suggest a vary difference between these countries in terms of the link of interest. Thus, the authors display the difficulty to implement the unique strategies in these countries. Pao and Tsai (2010) provide supportive evidence while utilizing the data for BRIC countries.

Al-Mulali and Che Sab (2018) have explored the link of interest in the case of Middle East countries. They have collected the data in the time span ranging from 1990 to 2008. The findings suggest a long-run link running from the emissions of CO_2 and electricity consumption to economic growth. The most important results of this paper suggest that electricity consumption and supply play a great role in economic development in the countries of interest. These findings are also supported by Al-Mulali (2011) in the case of MENA countries.

The panel data analysis is also conducted in the case of Mediterranean countries. The time period of interest covers the years between 1990 and 2016 (Kahouli, 2018). The findings suggest a unidirectional causal link between electricity and R and D stocks as well as between R and D stocks and CO_2 emissions. These findings are in accordance with Kobos, Erickson, and Drennen (2006) and Pfeiffer and Mulder (2013). Thus, the author suggests the necessity to increase the energy efficiency in order to decrease the environmental depletion. Besides those, there is a need to develop the energy supply based on the renewable sources.

Altinay and Karagol (2005) have explored the link of interest in the case of Turkey. The data are collected in the 50 years span between 1950 and 2000. The findings suggest a unidirectional causality from electricity consumption to the income. Thus, these results suggest that the electricity supply is of key importance to meet the electricity demand and to support sustainable economic growth.

These findings are supported by Soytas and Sari (2003). Nonlinear Granger causality between of variables of interest is explored by Nazlioglu et al. (2013). The link is confirmed in the both, short- and the long-run.

The literature review section clearly indicates the very poor empirical evidence on the link between electricity generation and CO_2 emissions at the World level as well as in the case of Turkey. Hence, this was a motivation to conduct this study and to try to provide the preliminary evidence on the topic. However, the findings tend to be of great importance for policy makers while developing and implementing energy strategies.

DATA AND METHODOLOGY

The database consists of the three time-series for the case of Turkey in the period 1974-2016. Electricity generation is approximated using the variable **ELC** that denotes the electricity generated from different sources, both renewable and non-renewables. It is expressed in gigawatt hours and downloaded from the OECD database. With regards to the CO_2 emissions, CO_2 emissions (metric tons per capita) – **CO** is taken as appropriate in this research. This data are collected from The World Bank. At last, **POP** is the proxy of population growth indicating annual population growth rate. This data is also collected from The World Bank.

The methodology will be summarized within eleven steps. The first step provides the most important measures of the descriptive statistics. In the next steps, we will explain the Toda Yamamoto approach. This approach is selected since it enables the variables to be integrated of different order or non-cointegrated. Toda and Yamamoto (1995) formalize the Granger causality test as following (Eq. 1 and 2):

$$y_t = \mu + \sum_{i=1}^{p+m} \alpha_i y_{t-i} + \sum_{i=1}^{p+m} \beta_i x_{t-i} + u_{1t} \ (1)$$

$$x_t = \mu + \sum_{i=1}^{p+m} \gamma_i x_{t-i} + \sum_{i=1}^{p+m} \delta_i y_{t-i} + u_{2t} (2).$$

The maximal order of integration is denoted by *m*, the optimal number of lags of

$y_t y_t$ and $x_t x_t$ is denoted by *p*. No autocorrelation is assumed as well as the normal distribution of error terms. To proceed to the Toda and Yamamoto approach there is a need to determine *m*. This approach may be summarized within the following steps.

In the first out of these steps, the presence of unit root will be tested. For this purpose, this paper suggests the Augmented Dickey-Fuller-ADF (Satrovic, 2017) and Phillips-Perron-PP tests. Both of the tests outline the non-stationary under the null hypothesis. The estimation of the regression to follow (Eq. 3) is the basis for the ADF test (Said and Dickey, 1984):

$$y_t = \beta' D_t + \varphi y_{t-1} + \sum_{j=1}^{p} \omega_j \Delta y_{t-j} + \varepsilon_t \quad (3)$$

where $D_t D_t$ denotes the vector of deterministic terms, $\varepsilon_t \varepsilon_t$ is not autocorrelated. With regards to the PP test, Phillips and Perron (1988) formalize the test regression as Eq. 4:

$$\Delta y_t = \beta' D_t + \pi y_{t-1} + u_t \quad (4)$$

where $u_t u_t$ is I(0) and can be heteroskedastic.

In the step two, we assume the maximum order of integration to be $m'm'$. If the

variables are found to be I(1), in that case $m' = 1.m' = 1$. The next step will be to set up the model while using log levels rather than the first difference. Moreover, Akaike's information criterion (AIC) and the Hannan and Quinn information criterion (HQIC) will be used to determine the optimal number of lags *p*. Furthermore, there is a need to test for the specification of VAR model e.g. serial correlation. In the sixth step, VAR model will be estimated while introducing the

selected number of the lags $m'\,m'$ (Eq. 5 and Eq. 6).

$$y_t = \mu + \sum_{i=1}^{p'+m'} \alpha_i\, y_{t-i} + \sum_{i=1}^{p'+m} \beta_i\, x_{t-i} + u_{1t} \quad (5)$$

$$x_t = \mu + \sum_{i=1}^{p\prime+m\prime} \gamma_i \, x_{t-i} + \sum_{i=1}^{p\prime+m\prime} \delta_i \, y_{t-i} + u_{2t} (6).$$

All other steps will test for the Granger causality and make some inference. The inference will be made taking into account that the null implies non-causality.

EMPIRICAL RESULTS

There are eleven steps that we will be followed while presenting the results of this empirical study. In the first step we provide the descriptive statistics of the variables of interest. The maximum value of the electricity generation is recorded in the last observed year while the minimum value is displayed in the first year of interest. In terms of CO_2 emissions, we make the same conclusion as of electricity generation. At last, the maximum population growth is recorded in the year 1974 while the minimum is reported in the year of financial crisis (2008). These findings are summarized in the Table 1. As of the most important measures of summary statistics it is important to emphasize a direct link between electricity consumption and CO_2 emissions which is quite expectable. However, the reciprocal link is displayed between the population growth and other two variables of interest.

Table 1. Descriptive Statistics

stats	ELC	CO	POP
mean	102141.30	2.98	1.75
sd	77794.31	0.93	0.361
max	261937.00	4.63	2.37
min	12846.00	1.59	1.20
skewness	0.59	0.19	0.41
kurtosis	2.02	1.86	1.81

Source: *Authors*

In the steps two and three, we aim to determine the order of integration of the variables of interest. To ease the interpretation, the natural logarithm of the variables is calculated and applied in the research to follow. In order to provide the evidence on the order of integration, we have employed the two tests respectively (Augmented Dickey-Fuller-ADF and Phillips-Perron-PP test). Table 2 summarizes the findings of ADF test. The findings suggest no rejection of the null hypothesis on unit root for all three variables in log level. Thus, we have also tested the presence of unit root at the first difference. These findings suggest I(0) for all three variables of interest i.e. variables are stationary for a 1% level of significance.

Table 2. Augmented Dickey-Fuller (ADF) Test

Variable		Test Statistics	1% Critical Value	5% Critical Value	10% Critical Value
lnELC	Z(t)	-0.714	-4.233	-3.536	-3.202
	MacKinnon approximate p-value Z(t) = 0.9722				
D.lnELC	Z(t)	-4.119	-4.242	-3.540	-3.204
	MacKinnon approximate p-value Z(t) = 0.0059				
lnCO	Z(t)	-0.583	-4.233	-3.536	-3.202
	MacKinnon approximate p-value Z(t) = 0.1592				
D.lnCO	Z(t)	-6.313	-4.233	-3.536	-3.202
	MacKinnon approximate p-value Z(t) = 0.0000				
lnPOP	Z(t)	-0.182	-4.279	-3.556	-3.214
	MacKinnon approximate p-value Z(t) = 0.9918				
D.lnPOP	Z(t)	-5.912	-4.242	-3.540	-3.204
	MacKinnon approximate p-value Z(t) = 0.0000				

Source: *Authors*

The difference between PP and ADF test lies in the different treatment of correlation and heteroskedasticity. ADF test uses a parametric autoregression while PP test ignores serial correlation. Thus, to provide the additional evidence on the stationary properties we have also employed the PP test (Table 3).

Table 3. Phillips-Perron Test

Variable		Test Statistics	1% Critical Value	5% Critical Value	10% Critical Value
lnELC	Z(t)	-2.849	-3.641	-2.955	-2.611
	MacKinnon approximate p-value Z(t) = 0.0516				
D.lnELC	Z(t)	-5.393	-3.634	-2.952	-2.610
	MacKinnon approximate p-value Z(t) = 0.0002				
lnCO	Z(t)	-0.955	-3.634	-2.952	-2.610
	MacKinnon approximate p-value Z(t) = 0.7693				
D.lnCO	Z(t)	-6.377	-3.641	-2.955	-2.611
	MacKinnon approximate p-value Z(t) = 0.0000				
lnPOP	Z(t)	-1.551	-3.634	-2.952	-2.610
	MacKinnon approximate p-value Z(t) = 0.5082				
D.lnPOP	Z(t)	-2.086	-3.641	-2.955	-2.611
	MacKinnon approximate p-value Z(t) = 0.2502				

Source: *Authors*

The findings of PP test support ADF with regards to the log level variables. However, PP suggests the stationary properties of the first difference values of the electricity generation and CO_2 emissions. However, population growth is not found to be stationary at the first difference.

In the steps four and five, the appropriate number of lags for the VAR model is determined (Table 4). The Akaike's information criterion (AIC) and the Hannan and Quinn information criterion (HQIC) agree that the optimal number of lags is 6. Therefore, this estimation proceeds while employing the 6 lags.

Table 4. The Number of Lags Needed

lag	LL	LR	Df	p	FPE	AIC	HQIC	SBIC
0	55.9209				0.00001	-2.86059	-2.81454	-2.72998
1	232.293	352.74	9	0.000	1.4e-09	-11.9077	-11.7235	-11.3853
2	277.887	91.188	9	0.000	1.9e-10	-13.8858	-13.5635	-12.9715
3	295.351	34.928	9	0.000	1.2e-10	-14.3433	-13.8828	-13.0371*
4	307.729	24.757	9	0.003	1.1e-10	-14.5259	-13.9273	-12.8279
5	312.781	10.104	9	0.342	1.5e-10	-14.3125	-13.5757	-12.2227
6	332.448	39.333*	9	0.000	9.5e-11*	-14.8891*	-14.0142*	-12.4074

Source*: Authors*

Before proceeding to the causality links between the variables, it is of key importance to check for the model specification (VAR). Thus, we have tested for the serial correlation (step 6). Table 5 summarizes the obtained results. Null hypothesis implies no autocorrelation. Due to the fact that both p values are bigger than 0.05, it can be concluded there is no serial correlation at the first and second lag order for the 5% level of significance.

Table 5. Testing for the Serial Correlation

lag	chi2	df	Prob>chi2
1	9.7363	9	0.37225
2	3.9462	9	0.91492

Source: *Authors*

At last, steps 7-11 include testing for the causal relationship between the variables. Null hypothesis suggests no causal relationship between the variables. Table 6 displays the findings on the causal link between the variables of interest. In terms of the causal link running from the CO_2 emissions to electricity generation, p value of the test statistics is found to be more than 5%, thus the null hypothesis on no causal link cannot be rejected.

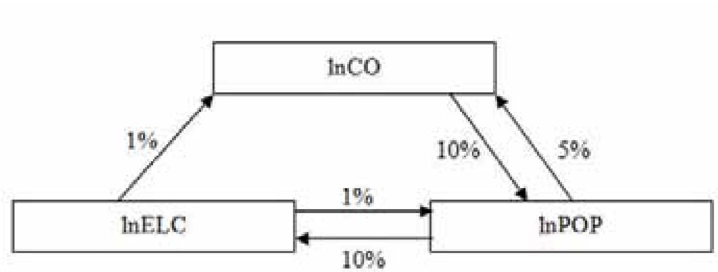
Table 6. Granger Causality Tests

Equation	Excluded	Prob>chi2
lnELC	←← lnCO	0.293
lnPOP	←← lnCO	0.072
lnCO	←← lnELC	0.003
lnPOP	←← lnELC	0.005
lnELC	←← lnPOP	0.081
lnCO	←← lnPOP	0.046

Source*: Authors*

These findings suggest that, CO_2 emission does not cause the electricity generation. This is quite expectable taking into account the fact that variable electricity generation includes electricity generated from all sources, both non-renewable and renewable. Thus, it will be of key importance to analyze separately the causal link between electricity generated from non-renewable resources and CO_2 emissions and renewable resources and CO_2 emissions. This will provide more reliable link on the relationship of interest. This cannot be estimated in this research due to the data availability issue. Hence, this is the recommendation for the future research. In addition to the tabular presentation, Figure 3 maps the causal links between the three variables of interest.

Figure 3. Causality Direction



Source: *Authors*

Figure 3 and Table 6 suggest a unidirectional causal link significant at 10% running from CO_2 emissions to population growth and from population growth to electricity generation. Moreover, unidirectional link significant at 5% is displayed from population growth to the emissions of CO_2. At last, electricity consumption is found to have a unidirectional link with population growth significant at 1%. Thus, the overall conclusion suggests a bidirectional link between population growth and CO_2 emissions as well as between population growth and electricity generation. However, only unidirectional link running from electricity generation to the emissions of CO_2 is outlined in the empirical research for the case of Turkey.

CONCLUSION

This empirical research aimed to investigate the potential causal link between electricity generation and CO_2 emissions while controlling for the population growth in the case of Turkey. The data are collected in the period between 1974 and 2016. With regards to the methodology, this paper employs Toda and Yamamoto approach.

The most important findings of this paper suggest a unidirectional causal link running from electricity generation to CO_2 emission. These findings suggest that, CO_2 emission does not cause the electricity generation. This is quite expectable taking into account the fact that variable electricity generation includes electricity generated from all sources, both non-renewable and renewable.

Moreover, the results suggest a bidirectional causal link between electricity generation and population growth. These findings imply that population growth stimulates the electricity generation. This result is also in accordance with expectation, since more intensive population growth demands more electricity and thus stimulates the electricity generation. In addition, electricity generation tends to stimulate the population growth. This is since some of the countries in the World have big problems with electricity supply. It influences negatively manufacturing sector, educational sector as well as many other sectors. This reason can cause some migrations and inflow in the countries with desirable electricity supply.

In addition, a bidirectional link between population growth and CO_2 emissions are recorded. More population is expected to demand more working place, and firms especially those in industry sector are known as significant energy gluttons. Moreover, by doing everyday activities, such as house works, transportation, education etc. more intensive population contributes significantly to CO_2 emissions.

These findings may be of great importance for policy makers. At first, unidirectional causal link running from electricity generation to CO_2 emissions is an alarm to start seriously thinking about the alternative sources of energy e.g. renewable sources. This is even more important in the case of Turkey, since most of the energy is imported and energy demand increases exponentially. As an argument for the need of renewable energy is the fact that this energy is cheaper and Turkey has a great potential especially in terms of solar and wind energy (Satrovic, 2018). Thus, small and middle projects in some of the cities can be easily employed. Second, there is a need to work on the attractiveness of business climate to be able to attract more foreign direct investors who will support the renewable energy projects. Third, with regards to the non-renewable sources there is a need to improve the energy efficiency as well as to find a way to reduce CO_2 connected with the devices using energy obtained from non-renewable sources. Lastly, there is a need to educate the population on the advantages of renewable energy as well as to provide some ideas to improve energy efficiency in households.

The recommendations for future research include the separate analysis of the causal link between electricity generated from non-renewable resources and CO_2 emissions and renewable resources and CO_2 emissions. Besides that, the role of energy consumptions by the sectors should be taken into consideration. At last, the potential role of financial crisis 2007-2008 tends to have a significant role while analyzing the variables of interest.

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