Quantify the Impact of Innovation and Supply, Tranformation, Consumption of Electricity on Economic Development Across EU Countries

Florin VĂDUVA (florin_vaduva@yahoo.com)
Titu Maiorescu University, Bucharest, Romania

Rodica GHERGHINA (rodica.gherghina@fin.ase.ro)
Bucharest University of Economic Studies, Romania

Ioana DUCA (ducaioana@yahoo.com)
Titu Maiorescu University, Bucharest, Romania

ABSTRACT

The objective of the research is to identify the impact of innovation and supply, transformation and consumption of electricity on economic development. In order to analyse the relationship between economic growth, innovation and energy consumption in EU countries, the regression technique was used. The output variable is Gross Domestic Product per capita computed for 26 countries across the EU. The explanatory variables are the potential factors that could have contribution to GDP growth of countries, as well as the innovation – measured by Global Innovation Index and Primary Energy Consumption. The result of research can be used in substantiation of public policies designed to boost the economic development of various countries.

Keywords: *economic growth, innovation, supply, transformation and consumption of electricity, GDP*

1.INTRODUCTION

In this century, the energy policy, through all its components, plays a major part in ensuring environmental sustainability. The electricity sector has come a long way in its progress towards a sustainable approach to electricity generation and supply, but it still has a long way to go. Although the level of investment in this sector has increased in the past years, it will need to maintain this trend for its objectives to be achieved. The forecast is that the electricity prices will increase in the next two decades, consequently decision-makers must minimise the pressure put on companies and consumers by way of decreasing costs and avoiding the policies' ineffectiveness.

Our research includes a review of the literature in the field of the researched topic, the research methodology, the database used in the research and the main empirical results, followed by conclusions.

2. LITERATURE REVIEW

The impact of innovation and energy consumption, especially electricity, is the object of numerous scientific research endeavours in the recent years. According to Platchkov and Pollitt, ”the economic engines, technologies and demand management are essential in understanding the long-term trends in the field of energy and especially the field of electricity consumption” (Platchkov and Pollitt, 2011). At the same time, „the energy policy in the current context should balance availability, the security of supply and environmental sustainability” (World Economic Forum, January 2015, pp.9).

In this context, in the modern society, „energy consumption is one of the drivers of economic growth, and electricity consumption, which is one of the most flexible types of energy, is a vital input in a country's socio-economic development”. (*Electricity consumption and economic growth in India Sajal Ghosh*, Indira Gandhi Institute of Development Research (IGIDR), Mumbai, India Received 2 September 2000*).

Another important and frequently analysed aspect is the extent to which certain policies for the rationalisation of electricity consumption of for tariff-setting may be implemented by governments if consumption is very different from one industry to another, and their contribution to the country's economic growth is also different.

As a matter of fact, the causal relationship between energy consumption and economic growth was the focal point of the research performed by several economists and public policies analysts beginning with the 1970s (Kraft and Kraft, 1978; Beenstock and Willcocks, 1981; Samouilidis and Mitropopulous, 1984; Yu and Choi, 1985; Erol and Yu, 1987; Cheng and Lai, 1997; Adjaye, 2000: Tsani, 2010; Acaravcı, Ozturk, 2010; Akkemik, Göksal, 2012; Adhikari, Chen, 2013).

In a study performed by Morimoto and Hope (Morimoto and Hope, 2001), the authors start from the model developed by Yang (2000) and, based on the research they performed, reached the conclusion that variations in electricity supply have a significant impact on the change in the real GDP in Sri Lanka.

Other authors, in the scientific research papers they elaborated, tackle the investment in innovation and technology, as well as its impact on economic growth and electricity consumption.

According to Narayan&Prasad, most research studies published in the field of energy policies confirm that „electricity consumption triggers economic growth both in developed countries and in emerging ones, which might mean that implementing electricity conservation policies would lead to decelerating economic growth” (Narayan, Prasad, 2008). The explanation derives from the fact that most countries depend economically on the industries with high electricity consumption levels.

In another study performed by Caraiani, Lungu and Dascălu, the authors „investigate the causal relationship between energy consumption and the GDP in European emerging countries in the interval 1980-2013 and perform an analysis in which they take into account stationarity, co-integration and causality tests, and the study results are mixed” (Caraiani, Lungu, Dascalu, 2015).

In a study titled ”*Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis”,* the authors analyse the connection between using ICT, economic growth and electricity consumption in OECD countries in the interval 1985–2012 (Salahuddin, Alam, 2016). The results confirm the fact that both the use of ICT and economic growth boost electricity consumption, both on the short and on the long term. The study emphasises at the same time that OECD countries have not yet achieved the maximum energy efficiency by expanding ICT. Efficient coordination, ICT expansion and the policies for the decrease in greenhouse gas emissions may potentially allow OECD countries to lower the risks. The use of green technologies is recommended as potential solution to decreasing electricity consumption triggered by the intensive use of ICT, especially in data centres.

3. RESEARCH METHODOLOGY

The objective of the research is to identify the impact of innovation and supply, transformation and consumption of electricity on economic development. The reasons why we decided to study the impact of these areas of the socio-economic life on the economic development are the following:

- Numerous studies have highlighted the positive impact of research on the economic development. Research, however, is a very complex area that incorporates the human factor, education, infrastructure, public policies, the business environment and its ability to capitalize research, the openness and capacity of financial institutions towards funding research etc. Taking these issues into account we considered that the global innovation index is one of the most representative indicators calculated on international level that captures the complexity of the innovation process. It is a composite indicator made up of 79 individual indicators coming from many various areas (see Figure 1), so that it could capture the complexity of the innovation process. Another reason why we chose this indicator is that, on The Global

Innovation Index website (https://www.globalinnovationindex.org/analysis-comparison), detailed information about the 79 indicators taken into account is given, on each country (even with the possibility to make comparisons between the countries). It is a useful instrument for adapting public policies so that it will improve the global innovation index indicator. Taking into account the above, we believe that by highlighting the impact the Global Innovation Index has on economic development can create a useful tool for public policy steerage.

- On international level there is a trend of changing the economic structure of countries by refocusing towards energy efficient economic activities. This is given by, on the one hand, the interest for reducing the pollution because, generally, energy intensive industries are polluting, while also the classic technologies of energy production are polluting. On the other hand, the industries that require lower energy consumption generally have a higher added value.

3.1 Description of regression model

In order to analyse the relationship between economic growth, innovation and energy consumption in EU countries, the regression technique was used. The output variable is Gross Domestic Product per capita computed for 26 countries across the EU. The explanatory variables are the potential factors that could have contribution to GDP growth of countries, as well as the innovation – measured by Global Innovation Index and Primary Energy Consumption and Supply, transformation and consumption of electricity.

Linear regression is a very powerful statistical technique. Linear models can be used for prediction or to evaluate whether there is a linear relationship between two numerical variables. The interest of regression analysis consists in finding a weighted combination of some set of variables that reproduces or predicts as well as possible the values that we have observed on the response or outcome variable. If this aim is achieved, the model we develop will predict well not only in the sample data set at hand but also in new data sets.

Regression analysis is used to describe the relationship between: a single response variable: Y, and one or more predictor variables: X1, X2,..., Xn.

In linear models, the response variable Y must be a continuous variable. The predictors X1,..., Xn can be continuous, discrete or categorical variables.

The equation for a linear regression is:

$$y_i = \beta_0 + \beta_1 \times x_{1i} + \beta_2 \times x_{2i} + ... + \beta_n \times x_{ni} + \varepsilon_i$$

Where:

(Y) Response variable

(X) Predictor/explanatory variables - xi denotes the i-th observation on the independent variable X.

Unknown parameters:

β_0 (Intercept): point in which the line intercepts the y-axis;

β_i (Slope): increase in Y per unit change in X.

They are assumed to be unknown parameters to be estimated from the data.

i=1,2,…,n.

The slope describes the estimated difference in the y variable if the explanatory variable x for a case happened to be one unit larger. The intercept describes the average outcome of y if x = 0 and the linear model is valid all the way to x = 0, which in many applications is not the case.

More broadly, if we have come close enough to identifying the true model (which, of course will still be only a crude approximation of the phenomenon we are studying), the science can move forward because we can then be pretty confident that the model is good enough to guide further research, clinical decisions, and policy. The remarkable acceleration in data analysis has been a direct consequence of improved computing power.

3.2. Description of the variables

Dependent variable (Y) - as the variable of interest in this study - is the **Gross domestic product (GDP per capita Euro)**

Independent variables (Xi) are considered the followings:

Global Innovation Index (GII) in 2014 was composed of 81 indicators. These indicators are divided into two categories: input and output indicators.

Input indicators come from five specific elements of national economies, which have a strong impact on innovation, namely: "*Institutions, Human capital and research, Infrastructure, Market sophistication, and Business sophistication*" (https://www.globalinnovationindex.org/about # -gii framework).

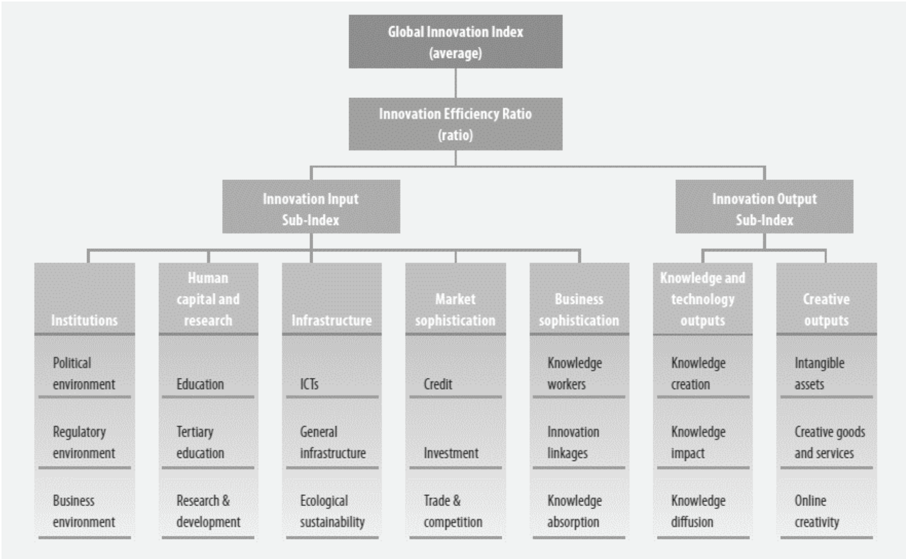
Output indicators are grouped into two categories, considered the effects of the innovation process: "Knowledge and technology outputs and Creative outputs" (https://www.globalinnovationindex.org/about # -gii framework). "

Based on these indicators are then calculated (Figure 1):

- **"Innovation Input Sub-Index**: is the simple average of the first five pillar scores
- **Innovation Output Sub-Index** is the simple average of the last two pillar scores
- **The Innovation Efficiency Ratio** is the ratio of the Output Sub-Index over the Input Sub-Index" (https://www.globalinnovationindex.org/about # -gii framework)
- **Global Innovation Index**: "is the simple average of the Input and Output Sub-Indices" (Dutta, Lanvin and Wunsch-Vincent, 2014, p.43).

Structure of Global Innovation Index

Figure 1



Source: https://www.globalinnovationindex.org/about-gii#framework

Other explanatory variable considered in the model is **Supply, transformation and consumption of electricity**. This indicator is noted in the multilinear regression model with the symbols STC_NRG. The analysed data are for 2014. To ensure the comparison between countries we considered variation of the indicator Electrical Energy Available for Final Consumption (Eurostat), compared to 2005. Energy statistics data covers all major sectors of the economy that are involved in the production, trade, energy transformation and energy consumption (the energy sector, industrial sector, transport, commercial and public services, agricultural/forestry/fishing and residential). According to Regulation (EC) No 1099/2008 on energy statistics „Energy supplied - electricity: consists in the sum of the net electrical energy production supplied by all power stations within the country, reduced by the amount used simultaneously for heat pumps, electrically powered steam boilers, pumping and reduced or increased by exports to or imports from abroad".

Prior to any analysis, the data should always be inspected for: Missing values, Outliers, Unusual (e.g. asymmetric) distributions, Changes in variability.

To ensure comparability between countries for GDP, the indicator GDP per capita will be used. The outliers were also removed from the sample (Luxembourg and UK and Czech Republic).

GDP per capita, Global Innovation Index and Primary Energy Consumption

Table 1

Country	GDP_per capita_2014_Euro	Glob_Innov_ Index_2014 (%)	Supply, transformation and consumption of electricity _2014 STC_NRG (%, 2005=100)
Belgium	35900	51.69	100.4
Bulgaria	5900	40.74	107.8
Czech Republic	14700	50.22	101.6
Denmark	46200	57.52	91.5
Germany	37100	56.02	98.2
Estonia	15200	51.54	114.3
Ireland	41000	56.67	102.7
Greece	16200	38.95	97.2
Spain	22400	49.27	93.7
France	32200	52.18	97.7
Croatia	10200	40.75	102.9
Italy	26500	45.65	93.6
Cyprus	20400	45.82	100.1
Latvia	11800	44.81	114.9
Lithuania	12400	41.00	115.8
Hungary	10600	44.61	110.5
Malta	19000	50.44	109.4
Netherlands	40000	60.59	98.6
Austria	38500	55.01	105.3
Poland	10700	40.64	119.4
Portugal	16700	45.63	97.6
Romania	7500	38.08	108
Slovenia	18100	47.23	97.8
Slovakia	13900	41.89	105.7
Finland	37600	60.67	97.7
Sweden	44400	62.29	93.5

Source: Eurostat and The Global Innovation Index 2014

4. RESEARCH RESULTS

The regression command is *lm* for linear model. We will store that model in a variable called linear_regression. The dependent variable is followed by a tilde "~" followed by the independent variable.

In R (Alexandru, Caragea, 2016) the *lm* function computes the coefficients. The output includes a conventional table with parameter estimates and standard errors, as well the residual standard error and multiple R-squared. Multiple R^2 measure the strength of the relationship between the set of independent variables and the dependent variable. An F test is used to determine if the relationship can be generalized to the population represented by the sample. A t-test is used to evaluate the individual relationship between each independent variable and the dependent variable.

The function *plot* of regression model will produce a set of four plots:

- residuals versus fitted values
- Q-Q plot of standardized residuals
- scale-location plot (square roots of standardized residuals versus fitted values
- plot of residuals versus leverage that adds bands corresponding to Cook's distances of 0.5 and 1.

The multiple regression equation takes the following form:

$$GDP\_per\ capita\_2014\_Euro = \beta_0 + \beta_1 \times Glob\_Innov\_Index\_2014 + \beta_2 \times STC\_NRG\_2014 + \varepsilon_i$$

The estimated equation can be written as follows:

$$GDP\_per\ capita\_2014\_Euro = -1289.0 + 1391.2 \times Glob\_Innov\_Index\_2014 - 417.3 \times STC\_NRG\_2014$$

Coefficients interpretation

Table 2

Variables	Coeff. / Std. error
Intercept	-1289.0 (19115.6)
Glob_Innov_Index_2014	1391.2 (149.3)
STC_NRG_2014	-417.3 (141.0)

The coefficients estimates are b_0=-1289.0 (intercept), b_1=1391.2 (Glob_Innov_Index_2014) and b_2=-417.3 (STC_NRG_2014). The significance of the estimates is tested with the provided p-values. The null hypothesis for this test is that all coefficients are 0, but the p-value for each of the estimates is lower than 0.05 so we obviously reject this hypothesis and conclude that all the estimates can be distinguished from 0 and that the equation does have explanatory power.

The intercept is the expected mean value of the dependent variable when all independent variables are zero. So, if the variables Glob_Innov_Index_2014 and STC_NRG_2014 take both null values, the dependent variable GDP_per.capita_2014_Euro has a mean value of -1289.0 (Table 2).

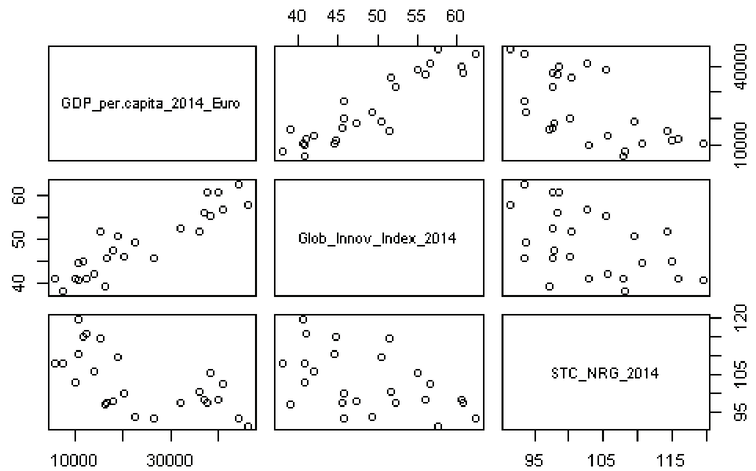
As the Global Innovation Index increases with one unit, the GDP per capita increases with 1391.2 Euro, when all other variables remain constant. As the Supply, transformation and consumption of electricity increases with one unit, the GDP per capita decreases with 417.3 Euro, when all other variables remain constant.

Measures of Fit Quality

- Coefficient of Determination, R^2 (Multiple R-squared: 0.8774). R^2 represents the proportion of the total sample variability explained by the regression model. That means the explanatory variables (Global Innovation Index and Supply, transformation and consumption of electricity) explains 87.74% of response variation (GDP per capita).
- Adjusted R^2 (Adjusted R-squared: 0.8662). The adjusted R^2 takes into account the number of degrees of freedom and is preferable to R^2.
- Here the p-value of the model is 9.411e-11 (<0.05), so reject the hypothesis that the slope is zero (in this situation, there is a correlation between variables, 95% confidence intervals).
- Pearson's product-moment correlation coefficients as a measure of the linear correlation between two variables indicate that the GDP per capita is strongly correlated with Global Innovation Index (0.9102, p-value = 2.788e-10) and also with Supply, transformation and consumption of electricity (-0.6274468, p-value =0.0007871); there are no collinearity between independent variables.

Colinearity Analysis

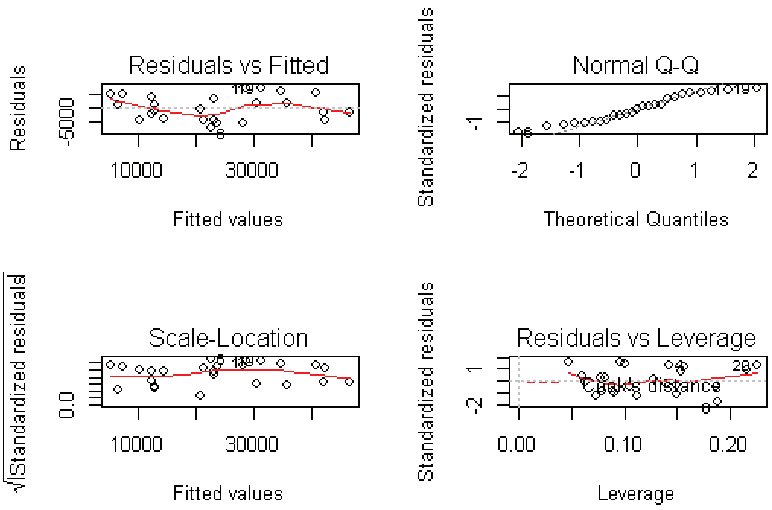
Figure 2



- The assumptions on the residuals needed to consider the linear model valid. We need an even scatter of residuals when plotted versus the fitted values, and a normal distribution of residuals. R produces 4 plots we can use to judge the model (fig. 3).

Residuals Analysis

Figure 3



Analysing the charts generated by software R it can highlight the following conclusions:

- Residuals are normal distributed, as the figure 3 (Normal Q-Q) shows.
- The “Residuals vs Fitted” chart show if there is a trend to the residuals. When a linear regression model is suitable for a data set, then the residuals are more or less randomly distributed around the red line. For the regression model presented in this study, the chart Residuals vs Fitted shows that the model is suitable for a data set.

5. CONCLUSIONS

In this research we have revealed the impact that innovation (Global Innovation Index) and power consumption (Supply, transformation and consumption of electricity) have on economic development (GDP per capita). Using multiple linear regression we have shown that two independent variables explain a rate of 87.74% evolution of the dependent variable.

The result of research can be used in substantiation of public policies designed to boost the economic development of various countries. In our opinion, the model developed in this research has a grate practical value because public policy makers have at their disposal a very useful benchmark tool for Global Innovation Index and his component indicators (see https://www.globalinnovationindex.org/analysis-indicator). These can give good orientation for public strategy and low framework in various fields like: political environment, regulatory environment, business environment, education, R&D, information and communication infrastructure, general infrastructure, ecological sustainability, credit, investment, trade and competition, knowledge workers, innovation linkages, knowledge absorption, knowledge creation, knowledge impact, knowledge diffusion, intangible assets, creative goods and services and online creativity.

As expected, the indicator Supply, transformation and consumption of electricity has an inversely proportional impact on economic growth. Developed countries implement technologies and develop electrical appliances becoming more efficient in terms of energy. Therefore, public policies should stimulate reduce energy consumption by fostering the development and acquisition of performance technologies and electrical appliances, not by reducing living standards as a result of not using this. In future research we intend to monitor this economic model because we believe that more technology reorients their areas so that changing from fossil fuel energy to electricity. This trend is present in auto industry. This guidance will result in an alert rhythm growth in electricity consumption which in our view will change the economic model.

REFERENCES

1. **Acaravcı, A., Ozturk, I.**, 2010, *„Electricity consumption-growth nexus: Evidence from panel data for transition countries"*, Energy Economics, 32, (3), 604-608.
2. **Adjaye, J., A.**, 2000, *„The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries"*, Energy Economics, 22, (6), 615-625.
3. **Alexandru, C., Caragea, N.**, 2016, "*RR by R in Official Statistics*", Romanian Statistical, Review, Vol.2.
4. **Akkemik, K., A., Göksal, K**., 2012, *„Energy consumption-GDP nexus: Heterogeneous panel causality analysis",* Energy Economics, 34, (4), 865-873.
5. **Beenstock, M., Willcocks, P.**, 1981, "*Energy consumption and economic activity in industrialized countries: The dynamic aggregate time series relationship*," Energy Economics, Elsevier, vol. 3(4), 225-232, October.
6. **Caraiani, C., Lungu, C., I., Dascălu, C**., 2015, *„Energy consumption and GDP causality: A three-step analysis for emerging European countries"*, Renewable and Sustainable Energy Reviews, Vol. 44, 198–210.
7. **Cheng, B., S., Lai, T., W.**, 1997, *„An investigation of co-integration and causality between energy consumption and economic activity in Taiwan"*, Energy Economics, 19, (4), 435-444.
8. **Dipa, A., Yanying, C.**, 2013, *„Energy Consumption and Economic Growth: A Panel Cointegration Analysis for Developing Countries*", Review of Economics & Finance, 3, 68-80.
9. **Dutta, S., Lanvin, B., Wunsch, S., V.,** 2014, *The Global Innovation Index 2014: The Human Factor In innovation*, Cornell University, INSEAD, and WIPO, second printing. Fontainebleau, Ithaca, and Geneva.
10. **Erol, U., Yu, E., S., H.**, 1987, *„Time series analysis of the causal relationships between U.S. energy and employment"*, Resources and Energy, 9, (1), 75-89.
11. **Kraft, J., Kraft, A.**, 1978, *„On the relationship between energy and GNP"*, Journal of Energy and Development, 3, 401–403.

12. **Morimoto, R., Hope, C.**, 2004, *„The impact of electricity supply on economic growth in Sri Lanka",* Energy Economics, Vol. 26, Issue 1, 77-85.
13. **Narayan, PK., Prasad, A**., 2008, „*Electricity consumption–real GDP causality nexus: evidence from a bootstrapped causality test for 30 OECD countries*", Energy Policy, 36 (2), 910–918.
14. **Platchkov, L., M., Pollitt, M. G.**, 2011, „*The Economics of Energy (and Electricity) Demand"*, EPRG Working Paper 1116, Cambridge Working Paper in Economics 1137.
15. **Yu, E.,S.,H., Choi, J.,Y**., 1985, „*The causal relationship between energy and GNP: An International Comparison*", Journal of Energy Development, 10, 249-272.
16. **Salahuddin, M., Khorshed, A.**, 2016, *„Information and communication technology, electricity consumption and economic growth in OECD countries: a panel data analysis",* International Journal of Electrical Power and Energy Systems, 76, 185-193.
17. **Samouilidis, J.E., Mitropoulos, C., S**., 1984, „*Energy and economic growth in industrializing countries: The case of Greece"*, Energy Economics, 6(3), 191-201.
18. **Tsani, S.**, 2010, „*Energy consumption and economic growth: A causality analysis for Greece"*, Energy Economics, 32, (3), 582-590.
19. World Economic Forum, 2015, "*The Future of Electricity Attracting investment to build tomorrow's electricity sector*", Industry Agenda, January, 2015, pp.9.
20. Eurostat - Database, available at: http://ec.europa.eu/eurostat/data/database, accessed on April 2017.
21. https://www.globalinnovationindex.org/analysis-comparison
22. https://www.globalinnovationindex.org/about # -gii framework
23. https://www.insead.edu/news/2014-gii-report