Erasmus University Rotterdam

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Master Thesis in Economics & Business – International Economics

Title: Growth, Pollution and Energy Security: a panel cointegration analysis on GDP, CO_2 emissions and Energy Imports.

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I - Introduction

Among the most important threats that endanger our society, climate change is becoming more and more important, since we can some of the consequences of that now, and some will become reality soon, in the following decades. According to the United Nations Framework Convention on Climate Change (UNFCCC), global warming should be limited to 1.5 °C in order to do not incur in irreversible changes. The potential consequences of an absence of response are rising sea levels due to poles de-frosting, harvest failures, droughts, heat waves, and last but not least, threat to health. The main determinants of climate change is pollution, and it consists of CO2 emissions and the so called "short-lived climate-forcing pollutant" (SLCPs), which include methane, black carbon, ozone and aerosols. These pollutants are the product of industrial production and consumption of goods and services by customers, and they have severe effect on our health. Seven millions premature deaths are caused by pollution according to the World Health Organization, and they are mainly concentrated in emerging economies, where low technological production infrastructure and high industrial activity are located. These figures are likely to get even worse if nobody plans a remedy to that.

Renewable energies are considered a possible solution to this problem: they do not pollute when consumed (even though their production is lightly pollutant), and it is possible to locate power generation facilities in rural and off the energy grid areas. According to Deloitte "Global Renewable Energy Trends" (2018), green power alternatives are becoming steadily more important in nationals' energy portfolios, encouraged also by falling cost of their infrastructure facilities. The reason of this change in the trend, again according to Deloitte, are related to two types of incentives that are those coming from the industry and those from the demand: industry contributes by offering technological advancement for more efficient and cheaper deployment of renewable energy, and the demand, which consists of consumers, by asking for this specific kind of energy, since it is free-pollutant. That is why renewable energy accounted for 19.3% of world energy consumption in 2017, based on REN21 (Renewable Energy Policy Network for the 21st Century) report analysis.

Pollution and health concerns are not the only drivers for renewable energy and their consumption; there exists a wide literature about Energy Security, which indicates the risks deriving from shocks of energy supply or its prices on the economy. Countries relying on energy imports are particularly susceptible to these shocks, but the energy crisis of 1973, when the OPEC members raised arbitrarily the crude oil prices, taught an important lesson also to those countries who felt safe from external shocks. In order to reduce the risk deriving from energy shocks, countries need to diversify their energy sources, or they need power sources located in their home territory. Nuclear energy has been a popular solution in the past, but the threat of potential disaster from the failure of a nuclear reactor, has led to discontinue nuclear power generation in many advanced economies. In addition, in this case renewable energy offers a solution to pollutant fuels and atomic energy, guaranteeing a clean and safe source of power, deployable also in rural areas off the national energy grid.

In order to have consumption of renewable energies, these have to be economically attractive, in order to have policies that supports their production, deployment and exploitation. In the literature, authors have been studying the relationship between renewable energy consumption and Gross Domestic Product, in order figure out are the potential benefit of these kind of energies on national income. This is a relatively new topic given the fact that data about this subject is still being gathered, and often we incur in lack of necessary data or completeness. Nevertheless, there exists a literature about the topic that agrees on the long-term positive effect of renewable energy consumption on nationals' accounts and economy, but when it comes to the analysis of the short-term dynamics of renewables consumption on the economy, we often incur in opposing conclusions. The reasons of that are related to the country, or the panel of countries the authors decided to analyze, or the methodology they adopted (cointegration vs. simple ordinary least squares). Nonetheless, given the threats coming from pollution, climate change and energy security, the actual benefits deriving from renewable energy consumption are easy to outline. As explained before, renewable energies could be an answer to the previously mentioned problems, since they reduced overall levels of pollutions and dependency from energy imports. In this way, countries would be able, for instance, to avoid increasing expenditure for the healthcare system due to pollution diseases, cost to mend disasters caused by climate change and less dependency on energy imports, which directly affects country's GDP.

For the reason above mentioned, the aim of this research is to demonstrate whether higher consumption of renewable energy has a positive effect on the economy, and investigate the short and long-run dynamics of this relationship. In order to account for pollution and energy security, CO_2 emissions and value of the energy imports will be included in the research, catching their effect on the main dependent variable GDP. The analysis will be carried out by means of panel cointegration techniques, which consists of recent procedures necessary to obtain consistent estimates in presence of non-stationary data. The research will be conducted over a panel of 30 economies, from 1990 to 2014. The country analyzed and the timeline have been chosen according to data availability and modeling reasons. The final findings of this study will show renewable energy consumption to have a long-run positive effect on country Gross Domestic Product. The error correction model will outline the short-run dynamics that occur year by year between the variable involved in the analysis, revealing that in the short run consumption of traditional energies still has a positive impact on the dependent variable GDP, but increases CO_2 emissions, where renewables decrease them.

The remainder of this paper is structured as follows: the Section II provides a quick overview of historical reasons of renewable energy development and its present situation; Section III provides the literature Review; Section IV an explanation of the Methodology adopted; Section V a brief description of data exploited. Lastly Section VI and VII the discussion of the results and conclusions, lastly References.

II – Development and trends of renewable energy in Eurasia

There renewable energy sources in the Eurasian area consist of solar, hydro, wind, biomass, geothermal and biofuels. In Europe, renewable energies options started being explored after the energy crisis of 1973, when the OAPEC members decided to raise crude oil price to support the Egyptian and Syrian action against Israel in the Yom Kippur War. In addition to that, embargos versus the supporters of Israel led to the outbreak of the energy crisis. The countries that were affected the most were those heavily reliant on energy imports. As stated by Nitsch, Krewitt, Langniss (2003), Europe has always been basing his energy supply on imports from abroad, and therefore, the consequences of the Middle-East conflict were severe.

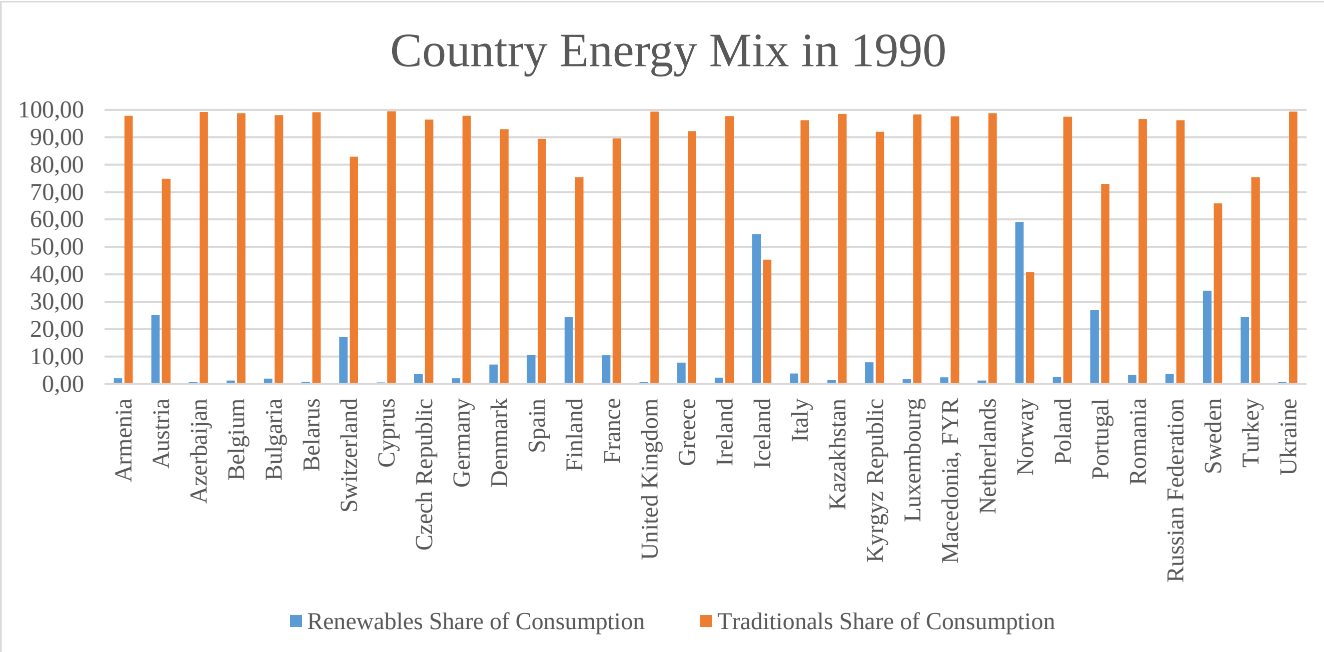
The consequences on the Asian economies that once were part of the Soviet Union and the Soviet Union itself were different, since they were able to meet their energy demand thanks to the crude oil sources in Siberia and Central Asia.

After the Yom Kippur War, the European countries started looking for alternatives to the fossil fuels: nuclear energy represented a valuable option for a long period, but the failure of the Chernobyl reactor of 1986, forced once again to look for other sources of power. The solution to the energy security puzzle were renewable energies.

Renewable energy consists of solar, wind, hydro, biomass and geothermal power that are consequently in electricity. Hydropower has always been an important power source in Europe, covering 30% of European electricity demand in 1970 (Nitsch, Krewitt, Langniss (2003)); solar and wind power were not as widespread as the hydro one, because to the high cost of their infrastructure.

Regarding the Asian countries, in the period from 1973 to 1990 renewable energies did not have much success because of the crude oil sources located mainly in Russia and in the old republics that once were part of the former Soviet Union. Since those sources were not under control of OAPEC members, they did not suffer the consequences of the energy crisis that was taking place in the rest of the world.

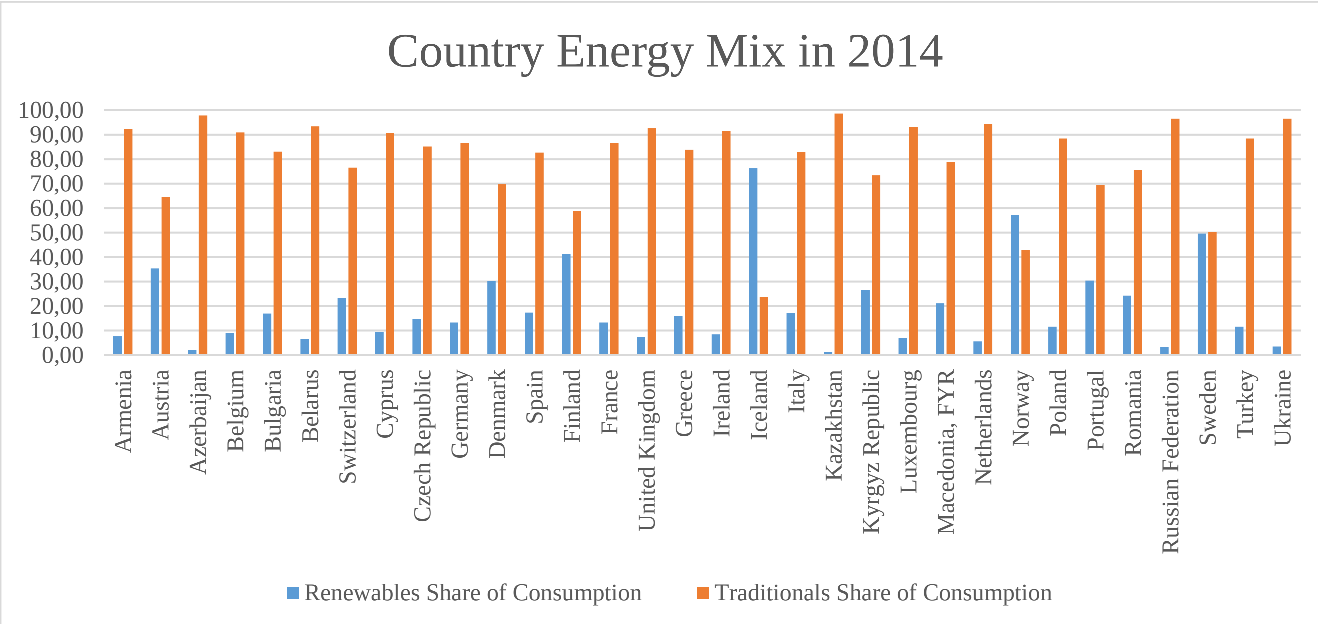
In 1990, the energy consumption profiles of the countries analyzed in the following paper were as shown in this graph:



The graph shows the shares of consumption of renewable and traditional energies over the total consumption in 1990. As we can see, many countries had interesting levels of consumption of renewable energies already in 1990: 55% of Icelandic energy demand was covered by means of geothermal waters; Norway even more to 60% thanks to the hydropower. The other countries did not manage to obtain comparable results.

As explained before, Russia and former USSR republics have low shares of renewable energy consumption.

In the last decade, the falling cost of photovoltaic solar panels, wind turbines, and the technological advancement, has provided again valuable incentives for the development of renewable energies. The same graph provided before, but in 2014, is as follows:



Eurasian economies still heavily rely on traditional energies, but compared to 1990, the shares of renewable energy consumption has increased significantly, and consequently, traditional energy share has decreased.

In 1990, Asian economies had almost no consumption of renewable energies, this has slightly change in 2014: this could be explained by environmental and health issues that are becoming more and more important across the world. Therefore, energy dependency is not the only driver of renewable energy deployment, there are also other factors (that will be explained in the literature review) that are pushing public opinion toward shift in favor of green and clean energy alternatives.

Nowadays, renewable energies in the European area are covering around 30% of the energy demand, and according to the IRENA's 2018 "Renewable Energy Prospects for the European Union" by 2030 this share could reach 50%, namely 1.476 terawatt-hours (tWh) of energy.

III - Literature Review

The relationship between renewable energy consumption and GDP is a fairly new topic in Energy Economics. In order to be able to investigate this relationship, we first have to outline the more general case of energy consumption (traditional and renewable jointly), since, as we will see, there could occur problems when interpreting the influence that each variable has on the others and when it comes the case of renewable energies.

The main question that authors usually ask themselves in this topic is about causality. When considering Energy Consumption and Gross Domestic Product, one could argue that is the first one to cause the latter, but also the opposite. The first case can be easily explained by resorting to the Cobb-Douglas function that suppose the production process relies on factors of production, which usually are capital (K) and labor (L). However, it is widely recognized that energy plays a relevant role in production processes as well as in national accounts. In this case, the Cobb-Douglas function would result as:

$$Q = AL^{\alpha}K^{\beta}E^{\gamma} \quad (1)$$

$$GDPcap = \beta_0 + \beta_1 TotalEnergyConsumption + \beta_2 K + \beta_3 L + \varepsilon \quad (2)$$

The first equation represents the Cobb-Douglas function in which L stands for labor, K for capital, E for energy consumption. A, β and γ are the intensities of the factors exploited during the production process. The (2) is the regression form of the Cobb-Douglas function, where GDPcap indicates Q, the βs are estimates that indicate the effect they have on the dependent variable GDPcap (Q), captured in equation (1) by α, β and γ.

The Cobb-Douglas function suggests that energy consumption determines GDP, or, a higher (lower) energy consumption causes GDP to grow (decrease). This finding has been supported by many researches. One the first papers that examines this relationship has been made by Kraft & Kraft (1978), when they found that energy consumption has determined GNP for the United States, and similar results have been found by Fang (2011) for China, Akinlo (2008) for a set of sub-Saharan economies, Chiang & Lee (2005) for a panel of 18 developing countries. These studies have in common that their methodologies are based on panel cointegration techniques, which allows the analysis of variables that are non-stationary.

As explained before, causality has been found also running in the opposite direction, saying that GDP growth (decrease) causes energy consumption to increase (decrease). The reasons why we find this relationship in reality are easily identifiable: as GDP grows, consumers ask for more services, industries require more factors of production, including energy. Therefore, we expect a higher energy demand and eventually consumption. This conclusion have been supported by Sadorsky (2009a, 2009b) when he studied a panel of emerging economies and the group of G7 countries respectively, including also CO_2 emissions as regressor to determine Renewable Energy consumption. In an important research, Asafu-Adjaye (2007) found that in India, Indonesia, Thailand and the Philippines Gross Domestic Product variations causes changes in energy consumption. In a similar manner Chontanawat (2008) found that causality from energy to GDP is more prevalent in OECD countries, and the opposite in non-OECD ones. His conclusions help to understand that shocks to the energy supply are likely to have greater impact on developed countries rather than those developed.

The first part of this section has explained the relationship that occurs between energy consumption and Gross Domestic Product, focusing on their causality linkages. However, when considering renewable energies, some of the assumptions summarized before does not hold anymore: for example, one would be entitled to ask why an expansion of the economy should increase renewable energy consumption and not the traditional energy consumption, or why a greater consumption of renewable energy should foster the economy. Therefore, the previous assumption has to be analyzed under the perspective of renewable energy in order to capture its effect on national economy, by first explaining why this kind of source of power is attractive for many countries in the world.

The relationship outlined in the Cobb-Douglas function (1), can be modified in order to take in account renewable energies. By substituting E^{γ} with RE^{γ} and$TE^{1-\gamma}$, we decompose the generic energy consumption assumed in (1) in its subcomponents that are renewable and traditional energy consumption. The exponent γ and 1-γ indicates that in the production process there is a mix of the two types of energy in such a way that together they fulfill the factor requirement of the process (because 1- γ + γ has to be equal to 1). The modified Cobb-Douglas function results as:

$$Q = AL^{\alpha}K^{\beta}RE^{\gamma}TE^{1-\gamma} \tag{3}$$

Where the terms RE and TE stands for Renewable Energy and Traditional Energy consumption respectively, γ and 1-γ are their intensity during the production processes. The new Cobb-Douglas function no longer analyses the overall consumption of energy, but its renewable and traditional subcomponents, and allows us to identify the effect of a percentage increase in the consumption of renewables. Why shares of consumption? Because if we analyzed the energy consumption if kilo-watt hours form, we would end up finding that any increase in the consumption of energy would foster GDP, but that would not be completely correct, because energy is always a factor of production.

The factor intensities are not the only channels through which renewable energy consumption influence national GDP: according to Chien & Hu (2006), the exploitation of renewable energy in the production process significantly and positively affects the Technical Efficiency Index (TE) of the 45 countries analyzed in their research. The higher the TE is, the more efficient will be the consumption of energy during the production process, and therefore more goods and services will be provided for the same amount of energy.

In addition to that, Burke & Davis (2018) conducted an investigation of the potential financial costs over a panel of different countries for two different scenarios: the first, in which countries do not put efforts in containing CO2 emissions, leading to a +2° of the world temperature. The latter in which measures are undertaken to contain the rising world temperature that consists of an increase of 1.5°. The authors showed that investing now to prevent climate change results in saving 20 trillion US dollar to pay in the future to remedy the consequences. The results of Burke & Davis (2018) are even more relevant if we consider the International Energy Agency report of 2006:

they projected that by 2030 the primary world energy demand will grow by 50% led by emerging economies, and so also the CO2 emissions, even though at a different degree.

The previous two examples outline the reasons why many countries in the world are switching to renewables source of power. The "*Global Trends in Renewable Energy Investment 2018*" issued by the Frankfurt School of Finance & Management in collaboration with the United Nations Environment Department, shows us that worldwide investments in renewable energies have been steadily growing from 2004 to 2017, from 47 billion reaching a total of 2.9 trillion of US dollars, increase driven also by the fall of solar panel infrastructures.

What happens in the case of an increase of GDP? Why should we expect an increase of renewable energy consumption, and what are the reasons of that? On October 19th of 2017, the Lancet Commission on Pollution and Health (part of the Global Alliance on Health and Pollution, which is an organism composed among the others by the World Bank, European Commission, Asian Development Bank) that shed light on the costly impact of pollution on nationals' accounts. They found that in 2015 pollution was responsible for 16% of all global deaths, and that 92% of these casualties took place in poorer nations that did not manage to work on reducing pollution. The economic cost of pollution stands "at 4.6 trillion US dollars per year, or 6.2% of global economic output" according to the Lancet report. Since 1970, working on reduction in the U.S. has costed 65 billion dollars, but they received back 1.5 trillion in benefits. Therefore, fighting the consequences of pollution and climate change is an expensive war that brings huge human and financial costs, and thus, countries have many incentives to invest in clean renewable power sources.

Another important issue related with renewable energy is energy security. The International Energy Agency (IEA) defines energy security as " the *uninterrupted availability of energy sources at an affordable price*", meaning that country's supply of energy is resilient to supply and energy price shocks. Concerning traditional energies, nations without natural endowments of resources, have to rely on imports from other countries to meet their energy demand. This also means that their economy is susceptible to external shocks and arbitrary changes in energy/petrol/gas prices due to policy changes. Renewable energies represent a way to overcome this issue, they are largely available in any country, and moreover, their infrastructures can be built locally and in rural areas, reaching also the less accessible part of a country that are outside the national power grid.

The standard Gross Domestic Product generation equation is as follows:

$$GDP = C + I + G + NX$$

Where C stands for expenditure for Consumption, I for Investments, G for Government expenditure to realize infrastructures and NX is the Trade Balance, which is the difference between Exports minus Imports. Energy imports enter the equation in the term "NX", and as they grow, the little becomes NX and consequently GDP should decrease. This equation explains why positive shocks to energy price have a detrimental effect on GDP.

Thus, potential future cost related to climate change and healthcare, combined with the management of energy security, offer in this period incentives to invest specifically in renewable source of power instead of traditional ones.

IV - Model and Methodology

Nelson & Plosser (1982) discovered that most of the macroeconomic time-series variables exploited commonly for research purposes, instead of being characterized by fluctuations around a deterministic trend, are actually non-stationary processes that after a shock will not revert to the original path of distribution. In addition to that, Stock & Watson (1989) argued that in order to get reliable results from causality tests, it is of the utmost importance to check for stationarity of time series.

These two facts explain why whenever we are analyzing time-series we have first to check for stationarity.

Stationarity vs. Non-Stationarity

Time series data is characterized by three properties. A stochastic process x is *Stationary* if for each t (period indicator) the joint probability distribution of x is the same as that of $x_{t1+h}, x_{t2+h}, \ldots$ The variable is *Covariance Stationary* if the expected value, variance and covariance are constant all over the distribution. Lastly, the *weak dependence* entails that x in time t becomes the less dependent from x_{t+h} the more h increases. These three properties together guarantee that the OLS estimator is consistent and that any regressor is independent from the error term.

Whenever we have a time series in which these three properties fail, we have a *non-stationary* stochastic process. In these cases, the joint probability distribution will change when a shock occurs, and therefore the Covariance Stationarity will fail as well.

When we want to check whether the distribution is stationary or not, we need to check for the presence of *unit-roots*. The most commonly adopted test to do so is the *Augmented Dickey-Fuller Test* (ADF). The procedure is as follows:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \cdots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t$$

Where α is a constant term, β the time trend, p indicates the lag order of autoregressive process which is usually decided through Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC). If we imposed α , $\beta = 0$ we would get a *random walk* with a drift. The unit root test is computed by calculating:

$$DF = \frac{\gamma'}{SE(\gamma')}$$

If the DF value is less than the critical value, we reject the null hypothesis $= 0$, namely the presence of a unit root.

For the sake of completeness, the "*Results and Discussion*" section will contain outcomes of several stationarity test that are the *Levin, Lin and Chu* (LLC), the *Im, Pesaran and Shin* (IPS) and the *Phillips and Perron* (PP).

The LLC differs from the ADF by adding several lags of the dependent variable in order to avoid serial-correlation issues: the reason of doing so is because the ADF, LLC and PP assume a common first-order autoregressive component between all the panel under analysis. On the contrary, the IPS assumes heterogeneous autoregressive component between all the studied panels, therefore would not incur in serial correlation

Integration and Cointegration

One way to get rid of unit roots is to differencing the distribution instead of analyze levels. That is, if we take the stochastic process x, by differencing $x_t - x_{t-1}$ we could get a stationary distribution. In this case the random variable x is said to be *integrated of order 1* or I(1) (a variable I(0) is a random walk), and is stationary only after differencing.

A second way to overcome the issues related to non-stationarity is by *Cointegration*. Two non-stationary time series distribution are cointegrated if exist a combination of them that is stationary. In time series analysis, the existence of this combination is important for two reasons: any deviation from the equilibrium will not be temporary, and secondly, as stated by Granger & Newbold (1974) and Phillips & Hansen (1980), if we ran a regression with non-stationary series, the OLS estimator would biased (non-asymptotic error).

Engle & Granger (1987) proposed a simple method, called *Engle-Granger Two-Step Method* to discover cointegration. Starting from the standard regression, want to find the residuals:

$$y_t = \beta x_t + u_t$$

$$y_t - \beta x_t = u_t$$

Where y_t, x_t are two non-stationary processes, and u_t are the residuals of the relation. Once we have u_t we can perform a unit-root test, as described in the previous part: if the residuals are stationary, we have a cointegrated relationship that is an equilibrium.

Pedroni (1999, 2004) has developed the specific cointegration test adopted in this research that allows for panel specific cointegrating vectors.

Fully Modified Ordinary Least Square, Dynamic Ordinary Least Squares and Panel Error Correction Model

Given the existence of a cointegrating relationship, it is possible to use panel cointegration techniques in order to get reliable estimates. The two model adopted in this research are the *Fully Modified Ordinary Least Squares* (FMOLS), designed by Phillips & Hansen (1990), which modifies the standard OLS to correct for serial correlation and endogeneity that naturally arises from a cointegrating relationship between variables, the *Dynamic Ordinary Least Squares*, proposed by Stock & Watson in 1993, that solves endogeneity by adding lags and leads; and lastly an Error Correction Model (ECM) (built on the basis of the residuals obtained by the FMOLS and DOLS) to investigate short-run dynamics.

Phillips & Hansen (1990) stated that "…*Cointegrating links between non-stationary series lead to endogeneities in the regressors that cannot be avoided using vector autoregressions, as if they were simply reduced forms*.", and with regards to the *Ordinary Least Squares* (OLS) "*… Estimates for any cointegrating relations are asymptotically second order biased in the sense that their limit distributions are mislocated or shifted away from their true parameters, even though their estimates are consistent"*. Consequently, the reason why the simple OLS does not fit cointegrating equation is that it does not take in account long-run endogeneities in the regressors, and therefore, yields biased estimates. When analyzing a cointregrating relationship, is very important to take into account possible endogeneities, since it means that a regressor is correlated with error term of the model. Endogeneity could arise due to several reasons, but according to the literature about energy consumption and gross domestic product, the responsible seems to be Simultaneity. That is, if we consider our regressors and the dependent variable, we can say that energy consumption causes Gross Domestic Product, but also the opposite way Gross Domestic Product causes energy consumption. When we find this situation we have simultaneity in the regressors, and it is likely the case to have endogeneity. A second implication of endogeneity is that invalidates one of the assumption of the Ordinary Least Squares, namely that all the regressors are uncorrelated with the error term, and consequently, we cannot guarantee the error term equal to zero.

Due to the reasons just mentioned, we can't adopt the simple OLS and proceed with the FMOLS and DOLS.

Starting from the basic model:

$$y_t = Ax_t + u_{0t} \tag{1}$$

With A representing a $n \times m$ coefficient matrix and x_t a $m = (m_1 + m_2)$ dimensional vector of cointegrated or stationary regressors. The FMOLS makes correction for endogeneity and serial correlation to the OLS estimator of (1). The endogeneity correction is made by modifying the independent variable y_t as follows:

$$Y_t^+ = y_t - \hat{\Omega}_{0x}\hat{\Omega}_{xx}^{-1}\Delta x_t \tag{a}$$

Where $Y_t^+$is the corrected variable, $\hat{\Omega}_{0x}$ and $\hat{\Omega}_{xx}^{-1}$ are kernel estimates for long-run covariances $\Omega_{0x} = lrcov + (u_{0t}, \Delta x_t)$ and $\Omega_{xx} = lrcov + (\Delta x_t, \Delta x_t)$.

Then, the serial correlation is corrected by:

$$\hat{\Delta}_{0x}^+ = \hat{\Delta}_{0x} - \hat{\Omega}_{0x}\hat{\Omega}_{xx}^{-1}\hat{\Delta}_{xx} \tag{b}$$

Where $\hat{\Delta}_{0x}$ and $\hat{\Delta}_{xx}$ are kernel estimates of the one-sided long-run covariance matrices $\Delta_{0x} = lrcov + (u_{0t}, \Delta x_t)$ and $\Delta_{xx} = lrcov + (\Delta x_t, \Delta x_t)$.

Lastly, merging (*a*) and (*b*), we get the *Fully Modified Ordinary Least Squares* estimator:

$$\hat{\Delta}^+ = \left(Y^{+'}X - T\hat{\Delta}_{0x}^+\right)(X'X)^{-1} \tag{2}$$

Stock & Watson (1993) proposed a brand-new estimator for cointegrating relationships, which after Monte Carlo simulations proved to be as consistent as the Fully Modified OLS estimator. The estimating procedure designed by the authors, known as *Dynamic Ordinary Least Squared* (DOLS), has proven that by including lags and leads of the variables in the cointegrating relationship of interest remedies to simultaneity and small sample bias. A generic specification of this model could be written as follows:

$$Y_t = X_t B_t' + \sum_{i=-m}^{i=m} \alpha_i \Delta ElCons_{t-1} + \sum_{i=-n}^{i=n} \beta_i\, \Delta\%RE_{t-1} + \sum_{i=-l}^{i=l} \gamma_i\, \Delta\%TE_{t-1}$$

Where Y_t is country *i* GDP, *ElCons* is per capita electricity consumption in *i*, *%RE* and *%TE* are respectively the consumption shares of Renewable Energy and Traditional Energy. M=[c, λ, η, δ], X=[1, $ElCons_t$, $\%RE_t$, $\%TE_t$], and lastly m,n,l are leads and (–m),(-n),(-l) are lags.

Engle & Granger (1987) proved that when we are dealing with a cointegrating relationship "*There always exists a corresponding error-correction representation which implies that changes in the dependent variable are a* *function of the disequilibrium in the cointegrating relationship as well as changes in other explanatory variables*". Therefore is important to investigate short-run dynamics through an error-correction model.

To this end, I set up panel Vector Error-Correction Model (VECM) in order to investigate the short-run dynamics occurring between the analyzed variables. A common error-correction model could be written as:

$$\Delta y_t = \beta_0 + \beta_1 \Delta x_t + \gamma EC_{t-1} + u_t$$

Where Δ denotes first-differences, EC_{t-1} is the error-correction component. If γ=0, then there no exists a long-run relationship. β_1 indicates the immediate effect that a change in x_t has on y_t. γ denotes the effect of a deviation of y_{t-1} from its equilibrium path. In this research, the error-correction component is obtained from the lagged residuals of the long-run relationship computed by FMOLS and DOLS.

The Error-Correction Model results as a system of the following equations:

$$\Delta GDP_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(I)}$$

$$\Delta REC_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(II)}$$

$$\Delta TEC_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(III)}$$

$$\Delta EMP_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(IV)}$$

$$\Delta GFK_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(V)}$$

$$\Delta CO2_t = \beta_0 + \beta_1 \Delta GDP_{t-1} + \beta_2 \Delta REC_{t-1} + \beta_3 \Delta TEC_{t-1} + \beta_4 \Delta EMP_{t-1} + \beta_5 \Delta GFK_{t-1} + \beta_6 \Delta CO2_{t-1} + ECT_{t-1} \quad \text{(VI)}$$

The βs coefficient (excluded β_0) represent the short-run reactions of the dependent variable after a change in the regressor related to a specific β. The model is in equilibrium when the following identity is validated:

$$Y = \alpha + \beta X$$

Which it means that all the above mentioned equations (from (1) to (VI)) have to be true. When a shock causes one the regressors to change, they will consequently affect the dependent variable: at this point the error correction term (ECT) will restore the long run equilibrium to offset the effect of the shock.

Lastly, one issue that often related to panel cointegration is the problem of spurious regression. Regarding the long-run equilibrium, the DOLS and FMOLS are designed to account for this problem, however, when it comes to the error correction model, we do not have the re-parametrization that has helped us before. When analyzing a cointegrating relationship in an Error Correction Model, variables have to be first-differenced in order to eliminate their trends and to achieve stationarity, and this procedure has also the side effect of solve the problem of a spurious relationship.

V - Data Description

Annual shares of Renewable and Traditional Energy consumption over total has been retrieved from the "World Bank Development Indicators". From the same dataset, CO2 emissions kg per capita tells us the impact of pollution on the main dependent variable and renewable energy consumption. The main dependent variable that is Gross Domestic Product in constant 2010 U.S. dollars and data about employment and Gross Fixed Capital Formation are from the "Penn's World Table 9.0" database. All the variables are in natural logarithmic form in order to easily identify the impact on the dependent variable as an elasticity.

The main dependent variable of this analysis will be the natural logarithm of Gross Domestic Product, computed in constant 2010 U.S. dollars, and has been retrieved from the "Penn's World Table" by Feenstra, Inklaar and Timmer of the Groeningen University. The regressors adopted are shares of consumption of renewable and traditional energy consumption (over total energy consumption), natural logs of employment and Gross Fixed Capital formation (in constant 2010 U.S. dollars). In order to account for pollution and energy security, natural logs of Carbon Dioxide emission per capita and Energy Imports as percentages of country's GDP, has been included in the list of regressors following the approaches of Sadorsky (2009a, 2009b) and Asafu-Adjaye (2000). The reason of the choice of shares of renewable and traditional energy consumption instead of their absolute value is because we want to infer the effect of a higher share of renewable energy consumption over the total and not the effect of what could be explained by a simple increase in the generic energy consumption.

For modeling and data availability reasons, the analyzed timeline spans from 1990 to 2014 and covers a panel of 31 that are: Armenia, Austria, Azerbaijan, Belgium, Bulgaria, Belarus, Switzerland, Czech Republic, Germany, Denmark, Spain, Finland, France, United Kingdom, Greece, Iceland, Ireland, Italy, Kazakhstan, Kyrgyz Republic, Luxemburg, Macedonia, the Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Sweden, Turkey and Ukraine.

As explained in the *Introduction* and *Literature Review* sections, Renewable energy consumption and its generation have been positively increasing in the last decade, driven by the public awareness of the issues coming from climate change and pollution. To give a better illustration of this, **Map 1** and **Map 2** offer respectively the *Yearly average increase of renewable energy consumption in country energy mix* and *Yearly average decrease in CO2 emissions*.

Map 1

In this map countries are indicated in three different shades of green, the darker means bigger increase in renewable energy consumption from the previous year, where lighter the opposite, and yellow even negative increases. This map is telling us that from 1990 to 2014 almost all the countries under analysis have on average increased their consumption of renewable energy to a specific extent (defined by the shades of green): however, since these are averages, it could be possible that during one year in a specific country there has been a negative increase in renewable energy consumption. These conclusions should be related to the initial levels of renewable energy consumption in a given country, meaning that (for instance) even though Iceland is marked with a lighter green compared to Italy, it does not mean that Italy is consuming more renewables compared to Iceland, it means that from 1990 to 2014 Italy has on average a higher yearly increase in renewable energy consumption, where probably Iceland does not need to do so.

Overall, we can see that in almost any country under analysis, renewable energy consumption has been a positive trend all over the continent.

Map 2

In **Map 2** is possible to have a sight at the yearly CO2 emission reduction all over the Eurasian area. As before, the shades of green reflect the reduction extent of polluting emissions: those darker has managed to reduce the levels by more than 2%, those lighter by a percentage between 0% and 1%. Conclusions made on the comparison between the two maps have to be made carefully, since, as we can see, increases in renewable energy consumption sometimes are accompanied by a reduction of CO2 emissions, and sometimes not. The are many reasons for that: if we for example take a look at Armenia, we see from Map 1 they are one of the top countries for what concern renewable energy consumption, contrastingly, they have increasing level of CO2. This puzzle in this case could be explained by a booming economy that produce more. Indeed, the Armenian economy in 2014 is five times bigger than it was in 1990 (w.r.t. Gross Domestic Product). In a similar manner, considering Romania.

This underlying mechanics are important to explain the dynamics that occur when analyzing the relationship between renewable energies and gross domestic product.

VI - Results and Discussion

As explained in the Model and Methodology part, since we are using time series panel data, we have to undertake unit root test to check whether our variables are stationary or not. The results of the tests are presented in **Table 1A**, and they show (as supposed by Nelson & Plosser (1982)) that all the variables exploited in this research contain unit roots, and therefore they are non-stationary.

Table 1A

Variable	Levin,Lin & Chu (LLC)		Im, Pesaran & Shin (IPS)		Aug.Dickey Fuller (ADF)		Phillips - Perron (PP)	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
GDP/cap	-4.22536	0.0000	1.66450	0.9520	54.7495	0.7884	40.8070	0.9895
ΔGDP/cap	-11.2066	0.0000	-10.8154	0.0000	236.676	0.0000	241.960	0.0000
REC	1.39758	0.9189	4.49598	1.0000	82.2710	0.0617	95.9149	0.0060
Δ REC	-23.1000	0.0000	-21.1642	0.0000	493.235	0.0000	475.015	0.0000
TEC	11.4358	1.0000	11.7003	1.0000	36.2487	0.9980	36.2487	0.9940
Δ TEC	-14.3259	0.0000	-14.4836	0.0000	357.445	0.0000	432.313	0.0000
Emp	1.52745	0.9367	4.50458	1.0000	48.9081	0.9186	45.1817	0.9642
Δ Emp	-8.30483	0.0000	-8.90242	0.0000	203.938	0.0000	198.653	0.0000
GFK	-1.93824	0.0263	1.07265	0.8583	49.4770	0.9092	39.1293	0.9940
Δ GFK	-13.9265	0.0000	-13.1313	0.0000	289.490	0.0000	359.615	0.0000
CO2/cap	0.56965	0.7155	1.51793	0.9355	87.2526	0.0283	69.0349	0.3112
Δ CO2/cap	-17.4671	0.0000	-17.5050	0.0000	410.114	0.0000	764.273	0.0000
En.Imp.	-3.88525	0.0001	-2.45069	0.0071	77.8157	0.0071	61.0008	0.1370
Δ En.Imp.	-14.2718	0.0000	-15.1981	0.0000	315.505	0.0000	437.868	0.0000

As can be seen in the first row of the table, four different stationarity tests have been undertaken: the Levin-Lin-Chu (LLC), the Im-Pesaran-Shin (IPS), the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP). In each test the null-hypothesis is presence of a unit-root and therefore non-stationarity. In order to reject the null-hypothesis the probability value has to be equal or smaller than 0.1, namely 10% confidence. If this is the case, the alternative hypothesis of stationarity has to be accepted.

As mentioned in the "*Model and Methodology*" section, for the sake of completion, the results of the LLC, IPS and PP stationarity tests have been provided as well.

The outcomes reveal that all the variables are non-stationary in levels, meaning that they have a unit root in their distribution. On the other hand, an analysis of the same stationarity test on the first difference of the same variables (labeled with Δ) are stationary. Therefore, each variable adopted in this study is integrated of order 1, or I(1). This last conclusion is very important, since it is a mandatory condition to run a cointegration test.

The results allow us to proceed to test whether a combination of these variables is stationary, and in order to do that we have to check for the existence of a cointegrating relationship. The results of the cointegration tests are shown in **Table 2A**.

Table 2A

Pedroni Residual Cointegration Test

Within-Dimension

	Unweighted		Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	3.334144	0.0004	3.910455	0.0000
Panel rho-Statistic	4.756917	1.0000	4.437320	1.0000
Panel PP-Statistic	0.493273	0.6891	-2.345468	0.0095
Panel ADF-Statistic	0.593426	0.7236	-2.562808	0.0052

Between-Dimension

	Statistic	Prob.
Group rho-Statistic	6.053348	1.0000
Group PP-Statistic	-5.320532	0.0000
Group ADF-Statistic	-4.042660	0.0000

Kao Residual Cointegration Test

	t-Statistic	Prob.
ADF	-6.246663	0.0000

Null Hypothesis = No cointegration; Alternative Hypothesis = Cointegration

The Pedroni's and Kao's tests on residuals to check for cointegration reveal that exist a long-run relationship between Gross Domestic Product, Renewable and Traditional energy consumption, Gross Fixed Capital formation, Employment and CO2 Emissions per capita and Energy Imports. The Pedroni's test is divided in two parts: the upper one, the "Within-Dimension" assumes that the auto-regressive component employed to run the stationarity test on the residuals of the cointegrating relationship is the same across the panel; the lower one, the "Between-Dimension", assumes it is heterogeneous across panels. The outcomes suggest that in most of the statistics we do have cointegration between the variables under analysis.

Similar to Pedroni, the Kao's is based on the analysis of the residuals of the relationship between the studied variables. It differs from the previous only by the inclusion of cross-section specific intercepts. The test's outcome strongly rejects the null-hypothesis of no-cointegration. Therefore, in view of the above, we are able to say that we have a cointegrating relationship.

The next step is to estimate the coefficients of this long-run relationship between the dependent variable and the regressors. For the reasons explained in the Model and Methodology chapter, *the Fully Modified Ordinary Least Squares* (FMOLS) and *the Dynamic Ordinary Least Squares* (DOLS) are used to estimate the parameter of the cointegrating relationship. The results are in **Table 3**.

Table 3

VARIABLES	(1) GDP/cap	(2) GDP/cap	(3) GDP/cap	(4) GDP/cap
REC	0.0372***	0.0433***	0.0386***	0.0646***
	(0.00222)	(0.00124)	(0.00579)	(0.00849)
TEC	-0.214***	-0.180***	-0.264***	-0.255***
	(0.0130)	(0.00725)	(0.0331)	(0.0480)
GFKformation	0.344***		0.377***	
	(0.00307)		(0.00851)	
Employment	-0.259***		-0.292***	
	(0.00707)		(0.0178)	
CO2 Emissions	0.310***	0.637***	0.253***	0.696***
	(0.00761)	(0.00393)	(0.0216)	(0.0281)
Energy Imports	0.00679**	-0.0303***	0.00822	-0.0268**
	(0.00322)	(0.00175)	(0.00836)	(0.0122)
Constant	1.049***	8.139***	0.733***	8.586***
	(0.0864)	(0.0332)	(0.233)	(0.218)
Observations	611	611	609	609
R-squared	0.992	0.970	0.999	0.995
Model	FMOLS	FMOLS	DOLS	DOLS
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Equations (1) and (2) report the FMOLS's outcomes, (3) and (4) the DOLS's ones. As we can see, the estimates obtained by the two different models are similar, and highly significant. Equations (2) and (4) show the results when not including some standard determinants of GDP that are Employment and Capital (labeled as GFKformation). Renewable energy consumption (lnREC) and Traditional energy consumption (lnTEC) have opposite effects on the dependent variable GDP: the first is always positive and significant, the second always negative and significant. These conclusions, even though they seem suggesting that renewable energy consumption is good for Gross Domestic Product, are puzzling. The positive coefficient of lnREC is in line with the literature analyzed in the *Literature Review*, as showed by Sadorsky (2009), Apergis & Payne (2009, 2010), Halicioglu (2009), however, the negative lnTEC coefficient contradicts the assumption made in the *Literature Review* regarding the Cobb-Douglas function. Since traditional energies are factors of production, they should foster economic growth, and on the contrary, the estimates suggests they have a detrimental effect on Gross Domestic Product. This last conclusions is in contrast with Apergis (2012), where he found that both the type of power consumption have a positive effect on country's GDP.

The other variables are in line with the literature and with our expectations: CO2 emission affect positively the economy, since they are, among the other reasons, the result of production and consumption of goods and services, and therefore they reflect an "active" economy. Energy Imports are comparable to the energy consumption case, since more energy, even though imported, can be treated as determinant for national GDP, as factor of production in a Cobb-Douglas function. Capital has positive coefficient, whereas Employment not, but only because both GDP and Employment are in capita form, and therefore we should expect a negative sign.

As a proof that the FMOLS and DOLS are a representation of a truthful long-run cointegrating relationship, we can analyze the residuals of these relationships and test again for stationarity. The results are in **Table 1B**.

Table 1B

Variable	Levin,Lin & Chu (LLC)		Aug.Dickey Fuller (ADF)		Phillips - Perron (PP)	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
FMOLS residuals	-8.70181	0.0000	181.652	0.0000	175.498	0.0000
DOLS residuals	-18.9430	0.0000	468.048	0.0000	508.856	0.0000

Null Hypothesis = Unit root; Alternative Hypothesis = No unit root.

Since both the FMOLS and DOLS residuals reject the null hypothesis for presence of unit root in each test, we can safely say once again that the exists a cointegrating relationship between the variable analyzed.

Finally, the residuals of the long-run equilibrium are adopted also to set up an Error-Correction Model that could uncover the short-run deviations from the long run equilibrium, and the speed at which the equilibrium is restored. In order to do that, we need first-differencing all the variables and lag all the regressors, and the lagged residuals will serve as error-correction terms.

Table 4

Dependent Variable		*Excluded Variable* ΔGDP	ΔREC	ΔTEC	ΔEMP	ΔGFK	ΔCO2	ΔEIM	ECT
(I)	**ΔGDP**	/	-0.009138	0.053743	-0.029341	0.013702	0.005597	0.019606	-0.010023
			(0.01190)	(0.07864)	(0.07332)	(0.01485)	(0.02748)	(0.01663)	(0.01157)
(II)	**ΔREC**	-0.623417	/	0.861025	-0.131916	0.116522	0.179083	-0.133129	0.087984
		(0.25532)		(0.33970)	(0.31670)	(0.06414)	(0.11871)	(0.07185)	(0.04997)
(III)	**ΔTEC**	0.121045	-0.011405	/	0.004231	-0.022844	-0.040005	0.028517	-0.019322
		(0.04194)	(0.00844)		(0.05203)	(0.01054)	(0.01950)	(0.01180)	(0.00821)
(IV)	**ΔEMP**	0.117248	-0.000945	0.054629	/	0.022457	-0.009247	-0.020044	0.015106
		(0.03548)	(0.00714)	(0.04721)		(0.00891)	(0.01650)	(0.00998)	(0.00694)
(V)	**ΔGFK**	0.332826	0.010188	0.335080	0.364158	/	0.026729	-0.100722	0.084652
		(0.20659)	(0.04158)	(0.27486)	(0.25626)		(0.09605)	(0.05814)	(0.04043)
(VI)	**ΔCO2**	0.480401	-0.006773	0.183825	-0.198069	-0.086379	/	0.108709	-0.068881
		(0.12542)	(0.02524)	(0.16687)	(0.15558)	(0.03151)		(0.03530)	(0.02455)
(VII)	**ΔEIM**	0.887987	0.039570	0.342967	-0.478334	-0.351819	-0.865563	/	-0.847977
		(0.23015)	(0.04632)	(0.30622)	(0.28549)	(0.05782)	(0.10701)		(0.04505)

P-values in parentheses. The latin number indicates the equation with the variable on the right as dependent. The variables on the first row are the regressors.

Equation (I) to (VII) constitute the Error-Correction Model in which we are interested in. Short-run causality is determined by the statistical significance of the coefficient of right-hand side variables, on the other hand, long-run causality is determined by the error-correction term. The error-correction term coefficient has to be significant in order to reject the null hypothesis of no long-run causality, and negative in order to revert to the long-run equilibrium after a potential shock. In order to avoid a variable to be treated either as dependent or regressor, it has to be excluded from the list of the independent variables, and this exclusion is reported with a slash (/).

Equation (I) reports the short-run dynamics occurring between Gross Domestic Product and the regressors: as we can see Renewable energy consumption is statistically significant but negative, meaning that affects negatively the dependent variable, whereas the consumption of Traditional energy make it increasing in the short-run (. Not surprisingly, CO2 emissions per capita and Energy Imports (EIM) have a beneficial effect on GDP, that could be explained by the fact that economic expansions come with higher pollution, and the opposite, and

Equation (II) considers the effect that the regressors play on the dependent variable REC, which is Renewable Energy consumption. Traditional energy consumption has a positive effect on renewables consumption : the higher emissions related to fossil fuels have the effect to increase renewable energy consumption. CO2 emissions show a positive coefficient, meaning that in the short term higher level of pollution incentivates a greater consumption of green alternatives. In addition to that, expansions of the Gross Domestic Product have a beneficial effect on the dependent variable: this result is in line with the assumption made in the Literature review. Energy imports show a negative coefficient: importing power from abroad reduces incentives to consume renewable energies.

Equation (III) studies the short term dynamics between traditional energy consumption and the regressors: GDP shows a negative coefficient, that could be probably explained by the preference of renewable energy consumption, since it offers valuable effects in the future. Higher consumption of renewable energy lower the consumption of traditional due to percentages, however, has to be mentioned that compared to the previous equation that a variation in the consumption of renewable energy decreases the consumption of traditional energy, whereas in the previous equation it actually increases the renewable ones. Therefore, the estimates tell us that in the short run there is a preference toward the consumption of clean energy by decreasing the consumption of those harmful for the environment. The negative coefficient for CO2 emissions demonstrates once again that pollution plays a relevant role in choosing the energy consumption mix of a country, and therefore it decreases the consumption of traditionals.

In equations (IV) and (V) we have as dependent variables two of the main determinants of GDP that are employment and capital (GFK). Regarding the effect of GDP, the findings are in line with the common theory and literature. When it comes to the effect on the two types of energies we see that renewables have a little adverse on employment, and instead the higher consumption of traditionals increases the occupation. Switching to clean energy impact on the energy industry by decreasing lightly the occupation, a deeper analysis of this dynamic could be helpful to determine the net effect on occupation in the energy due to changes in the preferences of consumption. Gross fixed capital formation is positively driven by the consumption of the two types of energy, however, since the estimate of TEC is not significant, we could argue that in this analysis REC foster investments.

The last two equations offers some insight on the effects of the regressors when CO2 emissions and Energy Imports are the dependent variables, although, most of the coefficient given their p-values are not significant, and only a few considerations can be made. Regarding CO2 emissions, renewable energy consumption and gross capital formation work have a significant negative effect on pollution. Instead, the positive coefficient of energy imports is probably due to a overall higher consumption of energy, and given the theory of the factor of productions proposed in the Literature review, we have higher emissions of CO2. For what concerns the Energy Imports, has to be mentioned that energy trading is not a prerogative of only the fossil fuels, also renewables can be traded, especially by those countries with a power surplus. Lastly, we can see Gross Fixed Capital formation decreases the imports, one reason could be that part of the investments are aimed to set up energy infrastructures of power generation and storage, and therefore, we expect less reliance on energy imports.

VII - Concluding Remarks

The aim of this research is to identify a relationship between Gross Domestic Product and consumption of renewable energy. In order to do that, both renewable and traditional energy consumption have been implemented in the analysis, and in addition to them, also CO2 emissions and Energy imports to account for polltion and energy security, two central problems that many countries in the world are facing and try to control. The structural analysis of the variables adopted has showed the existence of cointegrating long-run relationship between them, which has allowed to us to proceed with the estimation by means of panel cointegration techniques. The results, obtained using FMOLS and DOLS, reveal that renewable energy consumption in the long-run do affect Gross Domestic Product, whereas keeping consuming traditional ones has an adverse effect on country's economy. However, the main target of this research has not been investigating only the "final" effect of the regressors on the main dependent variable GDP, but also to uncover the short-run dynamics that occur this environment. The panel Error-Correction Model performed in the final part of the Results and Discussion reveals that in the short-run consumption of renewable energy has a detrimental impact on GDP (even if small) of the Eurasian considered in this study, where on the opposite consumption of pollutant ones it still brings some benefits to the economy from a GDP point of view.

Regardless, renewable energy consumption has been found determinant in fighting the two main issues mentioned in the Literature Review that are Energy Security and Pollution: the Error Correction Model proves that has consumption of clean energy increases, both Energy Imports and CO2 emissions significantly decrease, where consuming pollutant does the opposite. These results can be summarized by pointing out that despite the negative impact of renewables in the short-run, in the long-run they do offer to Eurasian countries incentives to invest in green alternatives with potential gains in their respective GDP. Moreover, when considering the energy related issues of pollution, climate change and energy security, renewables have been found significantly determinants to fight this problem. Eurasian countries should keep investing and promoting green energies in order to do not incur future potential costly risk to their economies, even though they seem not offering many economical benefits in the short-run. Hopefully, by doing that, we will manage to contain the detrimental effects of climate change, and guarantee a prosperous and liveable future to the world.

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