STATISTICA, anno LXXIII, n. 3, 2013

INVESTMENTS IN RENEWABLE ENERGY SOURCES: THE RELATIONSHIP WITH NUCLEAR POWER CONSUMPTIONS

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1. INTRODUCTION

The world economic growth of recent years is largely ascribable to the Far East countries and other countries such as, for example, Brazil, that are quickly passing the stage of development. Unfortunately, the overall economic growth is based on traditional fossil fuels and, particularly, on a return to significant use of coal resulting in increased CO_2 emissions arising from the energy sector (Jaccard *et al.*, 2003; Soytas and Sary, 2009), responsible, to a large extent, for climate change (Sadorsky, 2009). The Kyoto Protocol has tried to limit the total CO_2 emission and other greenhouse gases, addressing especially to the industrialized countries. More recently, international agreements in Cancun (Mexico, December 2010) have established the necessity for technology transfer to developing countries, reiterated the urgent need to limit CO_2 emissions to keep global temperature increase in the limit of 2°C. Regarding, in particular, the production of electricity, all technologies employed have some impact on the environment and therefore, beyond the normal economic considerations of reliability and safety, a special ethical responsibility towards future generations is required for focusing on the "footprint" analysis of the plant environment. Therefore, the negative environmental impact of the energy sector may be remarkably reduced by a larger share of renewable energy sources on total electricity generation, but they alone would not suffice to achieve sustainability and keep climate change manageable. Recently, the International Energy Agency (IEA) has identified a possible solution in increasing energy efficiency and in reducing CO_2 emissions. Given the long lead times for developing new technologies and given the characteristics of renewable sources, the IEA recommends the use of large nuclear facilities and technologies for carbon capture and storage (Philibert, 2011). In fact, some developed countries have reduced their CO_2 impact thanks to nuclear power plant deployment.

Nuclear power stations do not burn fossil fuels to produce electricity and consequently they do not produce damaging, polluting gases. Many supporters of nuclear power production say that this type of power is environmentally friendly and clean. In a world that faces global warming, they suggest that increasing the use of nuclear power is the only way to protect the environment and prevent catastrophic climate change (many developed countries want to reduce the use of oil and gas for the high price they reached). Nuclear power deployment is considerable in some countries. For example, France produces approximately 70% of electricity from nuclear plants and leads the world in nuclear power generating technology - proving that nuclear power is an economic alternative to the very polluting fossil fuel power stations.

A growing number of scientific works are dedicated to renewable energy sources and the impact of economic growth on its own sustainability in the medium–long perspective. Studies by Sary and Soytas (2004); Bradley *et al.* (2007); Apergis and Payne (2010) investigate the causal relationship between renewable energy consumption and economic growth in heterogeneous countries. Recently, Marques *et al.* (2010) analyze the drivers promoting renewable energy in European countries and they find that lobbies of traditional energy sources and CO_2 emission restrain renewable deployment. Evidently, the need for economic growth suggests an investment that supports, but does not replace, the installed capacity. Other Authors analyzed the nuclear energy sustainability to oppose the renewable sources. Matsui *et al.* (2008) examine role and potentials of nuclear energy system in a sustainable development framework. They argue that sustainable development is pursued through a policy of energy conservation and stress the importance that nuclear power plant plays in order to safeguard the environment. Fosberg (2009) suggests that the way forward must go through the integration of renewable energy sources, because nuclear power can meet the shortage of renewable energy. There is a lack of empirical works in the fields of investment in renewable energy source and, in particular, in the discrimination between countries which generate with nuclear plants and countries that do not have nuclear power plants.

The aim of this study is to investigate the investments in renewable energy in relation to the level of industrial production and energy intensity of production processes and the total carbon dioxide emissions. In addition, such investments between countries that do or do not use significant amounts of nuclear generation will be analyzed. This paper addresses these issues by means of a dynamic panel analysis of the investments in renewable sources in a sample of 29 countries with distinct economic and social structures as well as different levels of economic development. Sample includes OECD countries to which we have added some emerging economies: Brazil, China and India.
The organization of the paper is as follows: Section 2 describes data; Section 3 analyzes the energy policy of countries in the sample while in Section 4 we report the empirical results and discuss the policy implications. Section 5 concludes the paper.

2. Data and methods

The data are the annual time series, from 1980 to 2008, of Total Renewable Electricity Net Generation (REN), Gross Domestic Product in $2000 constant prices (GDP), Energy Intensity (EI), CO_2 emissions and, in the sample in which are included countries with electricity production based on nuclear power plants, the Nuclear Electricity Net Consumption (NUC). All data are from the *U.S. Energy Information Administration* (EIA). EIA is a statistical agency of the U.S. Department of Energy (DOE) and is one of the ten principal statistical agencies in the U.S. Federal government. It provides a wide range of information and data products covering energy production, stocks, demand, imports, exports, and prices. The database covers 217 countries. EIA has performance standards to ensure the quality of information it disseminates to the public, as reported in the Information Quality Guidelines [1]. The explanatory variables were selected from a wider set of variables, based on their explanatory strength showed from the analysis of different models and according to the parsimony criterion. Atmospheric emissions of CO_2 are one of the main factors of the greenhouse effect. The mainly responsible are considered developed countries. Obviously, the carbon dioxide emission is a proxy of environmental degradation and not the only responsible. The expected results are estimates with a significant positive effect. The more the emissions are, the more should be the investments. The presence of a negative effect emphasizes the persistence of an economy tied to fossil fuels, which is still unable to replace the traditional energy sources. The energy efficiency (the amount of energy required for the production of a unit of GDP) is another relevant variable we have included in the study. According to this coefficient, economies mainly related to the tertiary sector and those oriented to production efficiency's improvement, are characterized by a low intensity. A variable that takes into account the evolution of the energy efficiency of production processes that determine the level of GDP should be inserted in the model. There is no variable that directly measure this phenomenon. In this paper we have chosen to use energy efficiency as a proxy for energy efficiency production. In fact, its evolution in time is the measure of the processes leading to contain energy consumption per unit of product used. Its performance leads to affect both investment in nuclear energy, as well as those in renewable energy sources. Improving energy efficiency is the product of a technical process in the processes of production . The GDP is a primary variable in the economic measures and it is directly related to energy consumption. Also, it is the main growth indicator and it is used as a proxy of income (Sadorsky, 2009). Furthermore, the use of GDP per capita instead of GNP or total GDP seems appropriated, since we refer to electricity generation within the country. Generally, it is assumed that richer countries are able to better support investments in renewable sources, as there is a greater environmental awareness, and internationals agreements require them. However, costs of transformation or conversion of the power plants can be high for some countries and policy decisions may discourage investments. Evidently, not all aspects of a complex phenomenon like the investment decisions in renewable energy, can be disclosed in the present work. Some critical issues, such as the reprogramming of the energy plan, the identification of suitable sites and installations, problems related to the resident population, the environmental impacts, are not taken into account but are factors that can affect investment decisions and the installed capacity. Some variables, such as prices of raw materials (gas, oil, coal), were not included for several reasons. Firstly, there are differences between the prices actually paid by producers and the market prices. Secondly, we consider that the electricity demand is inelastic to price variation of raw materials. Finally, if investment decisions on renewable sources have been taken in response to the recent crisis of raw materials' prices (oil, gas and coal) then they can still be caught, because of the time necessary to make functional the new power plants or to convert existing ones. Different ways of evaluating the development of renewable energy source are proposed by the literature. One is to measure the replacement of the traditional energy sources in the total energy supply while a second method is to measure the total amount of renewable energy produced (Bird *et al.*, 2005). Marques *et al.* (2010) use the contribution of

[1] http://www.eia.gov/about/information_quality_guidelines.cfm

renewable to energy supply as a percentage of total primary energy supply while Carley (2009) uses the yearly logarithm of the renewable energy percentage of electricity generation. In our paper, we explain the investment in renewable energy sources (ShREN) as the ratio between renewable generation and Total Net Electricity Generation. For nuclear energy, we use the ratio between Nuclear Electricity Net Consumption (ShNUC) and Total Net Electricity Generation. In this way we take into account the full portfolio in electricity generation. In fact, the remaining part, not included in the model, is all ascribable to fossil fuel. The share of Renewable Electricity Net Generation can be considered a proxy of investments in renewable energy sources.

In order to reduce variability, GDP, EI and CO_2 are expressed through natural logarithm. Panel dataset of OECD countries and developing countries (Brazil, China and India) is used in order to limit the effect of the small time span of the aggregated data. In order to investigate the dynamic of renewable investments in countries with, or without, nuclear power plants, the sample can be split into two subsamples. The former which includes countries based on fossil fuel electricity generation, and the latter including the countries with electricity production based also on nuclear power plants. The differences in the investment choices and the need for sustainable energy development can be analyzed. The electricity generation stations based on renewable and nuclear sources can be considered complementary in terms of environmental impact and the investments in renewable energy sources can be conditioned by the presence of nuclear power plants.

The first subsample, including Austria, Australia, Chile, Denmark, Greece, Ireland, Israel, Italy, Luxemburg, New Zealand, Norway, Portugal, Turkey is made up of the countries that produce electricity without the use of nuclear sources. The second subsample comprising the countries with nuclear power plants: Belgium, Brazil, Canada, China, Finland, France, Japan, India, Mexico, Netherlands, South Korea, Spain, Sweden, Switzerland, United Kingdom and United States (given the lack of data, countries excluded by the OECD panel are: Czech Republic, Poland, Slovak Republic, Slovenia and Germany (which is not included because of difficulty in time series reconstruction until 1989). Accession candidate countries and enhanced engagement ones are also not considered. Most of the countries included in dataset are categorized as high income by World Bank. Only Brazil, Mexico, Chile and Turkey are categorized as upper middle income while China and India are in the lower middle income group.

3. Explanatory Analysis

Before analyzing the dynamics of the panel of countries, an exploratory analysis to highlight the evolution of the choices of their energy policy is conducted. For this purpose, we use Principal Component Analysis (PCA), employing the variables identified. To have a framework for the performance of countries considered in the 29 years between 1980 and 2008 is the main motivation of this decision. The values of the factor loadings are fairly stable over time, resulting in a distribution of the variables on the main floor that can identify a sufficiently plausible physical meaning of the two principal axes considered. In Table 1 , the results of the variability explained by two major axes in the years between 1980 and 2008 are reported.

Although the first two components account for about 70% of total variance, this is sufficient to highlight some features of the evolution of the energy choices made by

TABLE 1
Variability explained by first two principal components in the two years 1980 and 2008.

Factors	Eigenvalue	Total Variance (%)	Cumulative total Variance (%)
		1980	
1	2.152	43.033	43.033
2	1.192	23.840	66.873
		2008	
1	2.357	47.131	47.131
2	1.200	23.998	71.129

various countries. First, the distribution of factor loadings lends itself well to define the meaning of the axes and, consequently, the characteristics related to the four quadrants of the Cartesian plane. The first principal axis, opposing the variables on the scale of production (LnGDP), pollution (LnCO_2) and high energy intensity (LnEI) to the share of renewable sources (ShREN) compared to total energy production. As for the second principal axis, contrasts with the variables related to CO_2 emissions and energy intensity, compared to the shares of renewable energy production with low emission of pollutants, that is renewable and nuclear energy (ShNUC). Consequently, countries with a high production obtained with conventional pollutants, and energy inefficient should be placed in the first quadrant.

Countries with a less significant production, produced primarily with conventional production processes are in the second quadrant. Countries where a significant level of production is not achieved, however, even with an important application of renewable energy sources are placed in the third quadrant. Finally, the fourth quadrant is reserved for countries with a high production level obtained with a significant proportion of nuclear energy and, therefore, a low level of CO_2 emissions. The distribution of the countries considered in the plan shows a substantial stability over time with some notable exceptions which will be now mentioned.

Figure 1 shows the distribution of countries on the main factorial plane as it appeared in 1980. In the figure, the arrows indicate significant shifts in the positions of some countries. Such movements were observed within the 29–year period.

The first general consideration that emerges from the figure is the loss of share of world production from Western countries to the emerging reality of what can be considered as India, China, Brazil, Turkey and New Zealand. Equally we note that the number of countries gathered around the axis factor is relevant, which means that, at least with regard to the variables taken into account, they take sides energy choices not clearly defined. Some countries, however, show a clear dynamic:

- Brazil, China, India and Turkey show a great increase in their share of world production (especially India and China) provided by a low production efficiency and high rate of pollution from carbon dioxide. In particular, Brazil and, even more, Turkey, faced with a significant increase in production, seem to have definitely opted for conventional production processes;
- Japan, France and the USA seem to have seen reduced their production levels compared to their competitors on the international market by shifting their energy

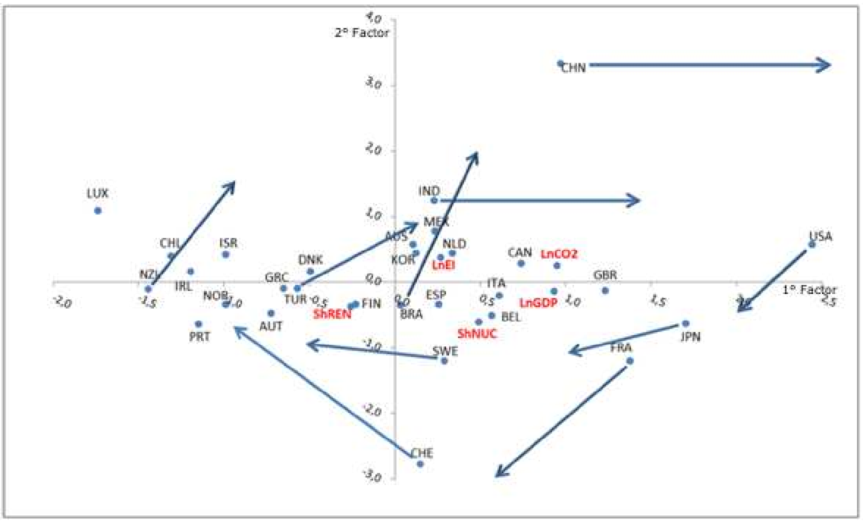

Figure 1 – Factor analysis. Distribution of countries considered in the work on the first factorial plane relative to 1980. The arrows indicate the most significant shifts observed in factorial plan of 2008.

choices even more, focused on the nuclear source. This is certainly evident with regard to France and Japan. For the USA, the situation in the years in between the two extremes shown in Figure 1, suggests an opportunity to consider the impact caused by the Three Mile Island accident, which probably hindered the development of nuclear sources;

- Sweden and Switzerland are two countries that leave the nuclear quadrant and definitely seem to have opted for renewable energy sources.

Essentially, factor analysis shows that the nuclear option does not privilege or particularly depress investment into renewable energy sources while it is quite worrying that in many countries the trend is to not renew their energy efficiency and to not invest in renewable energy with low pollution emissions.

4. Dynamic specification of renewable investments

We employ a panel dataset including 29 countries from 1980 to 2008. There are three main issues that can be solved using a panel dataset. In fact, a panel dataset allows us to have more degrees of freedom than with time–series or cross–sectional data, and to control for omitted variable bias and reduce the problem of multicollinearity, hence improving the accuracy of parameter estimates (Hsiao, 2003), having more informative data. The use of annual data also avoids the seasonality problems. Since static regression models can suffer from a number of problems, including structural instability and spurious regression (Song and Witt, 2000), in order to avoid these problems, dynamic specification of the equation that allows for slow adjustment has used in this paper. We estimate the following model:

$$y_{i,t} = \delta y_{i,t-1} + \mathbf{x}_{\mathbf{i,t}}^{'}\beta + \mathbf{u}_{\mathbf{i,t}} \tag{1}$$

where for country *i (i=1,...,N)* at time *t (t=1,...,T)*, δ is a scalar, $y_{i,t}$ is the investment in renewable energy sources, $\mathbf{x}_{\mathbf{i,t}}^{'}$ is a matrix of the independent variables while the error term

$$u_{it} = \alpha_i + \tau_{i,t} \tag{2}$$

follows a one–way error component model where α_i denote a country–specific effect, $t_{i,t}$ denotes a year–specific effect and $\alpha_i \sim IID(0, \sigma_\epsilon^2)$ and $\tau_{i,t} \sim IID(0, \sigma_\tau^2)$. However with this dynamic specification, it is faced that the correlation between the lagged variable and error term. One way suggested by Doornik *et al.* (2002) to solve this problem is to estimate a dynamic panel data model based on the Generalized Method of Moments (GMM) estimator proposed by Arellano and Bond (1991). In fact, several econometric problems may arise from estimating Eq. (1) (Baltagi, 2005):

- the variables in $\mathbf{x}_{\mathbf{i,t}}^{'}$ are assumed to be endogenous. Because causality may run in both directions these regressors may be correlated with the error term;

- time–invariant country characteristics (fixed effects), such as geography and demographics, may be correlated with the explanatory variables. The fixed effects are contained in the error term in Eq. (1), which consists of the unobserved country–specific effects, α_i, and the observation-specific errors, $\tau_{i,t}$;

- the presence of the lagged dependent variable $y_{i,t}$ gives rise to autocorrelation.

With these assumptions, the OLS estimator is biased and inconsistent (Baltagi, 2005) so in this work we employ the Generalized Method of Moments (GMM) estimator proposed by Arellano and Bond (1991), that includes lags of both the dependent and independent variables as instruments such that one can obtain optimal coefficients. The robustness of estimators is linked to the hypothetical cointegrating relationships among the reference variables: in particular, such estimates can be obtained whether the cointegrating relationship expressed by model is significant (stationary error) or not (integrated error). The consistency of the estimation depends on whether lagged values of the endogenous and exogenous variables are valid instruments in our regression. Furthermore, we may suspect that the explicative variables can have a delayed effect on the dependent variable due to a slow transmission mechanism. We have allowed for further lags in their estimation, but to restrict the size of the problem, we have limited the number of lagged levels (0, 1 and 2). They are also included as instruments for the predetermined variables. Hence the equation we estimate for non–nuclear sample is:

$$ShREN_{i,t} = c + (1+\beta)ShREN_{i,t-1} + \psi_1 LnGDP_{i,t} + \psi_2 LnEI_{i,t} + \psi_3 LnCO_{2;i,t} + u_{i,t} \tag{3}$$

where for country *i (i=1,...,N)* at time *t (t=1,...,T)*, $ShREN_{i,t}$ are the renewable investments, $LnGDP_{i,t}$ is the natural logharitm of GDP, $LnEI_{i,t}$ is the natural logharitm of Energy Efficiency and $LnCO_{2;i,t}$ is the natural logharitm of carbon dioxide emissions and u_{it} is the error component.

TABLE 2
Regression Results in the two samples.

Non Nuclear Countries		Nuclear countries	
Variables	Estimates	Variables	Estimates
$Constant$	-13.266[a]	$Constant$	-10.375[a]
$ShREN_{i,t-1}$	0.445[a]	$ShREN_{i,t-1}$	0.522[a]
$LnGDP_{i,t}$	0.459[a]	$LnGDP_{i,t}$	0.367[a]
$LnEI_{i,t}$	0.452[a]	$LnEI_{i,t}$	0.302[a]
$LnCO_{2;i,t}$	- 0.536[a]	$LnCO_{2;i,t}$	- 0.372[a]
		$ShNUC_{i,t}$	-0.161[a]
Sargan Test	302.9769	Sargan Test	385.8345

a: significant at 1%;

For nuclear countries, the equation is:

$$
\begin{aligned}
ShREN_{i,t} &= c+(1+\gamma)ShREN_{i,t-1}+\phi_1 LnGDP_{i,t}+\phi_2 LnEI_{i,t}+\phi_3 LnCO_{2;i,t} \\
&+ \phi_4 ShNUC_{i,t}+u_{i,t} \qquad (4)
\end{aligned}
$$

where the variables are the same of Eq. (3), and $ShNUC_{i,t}$ is the ratio of Nuclear Electricity Net Consumption. The estimation results for Eq. (3) and (4) are in Table 2.

Countries basing principally their electricity production on fossil fuels (ie non–nuclear countries) show the estimated autoregressive component significant at lag 1. We point out that the 1% increase in the level of renewable energy at time t-1 increases the same investment at time t of 0.445%, while GDP growth equates to an increase in the level of 0.459%. Also the energy intensity shows a direct relationship with investment in renewable energy sources. Only emission of carbon dioxide has an inverse relationship with the outcome variable, as expected. Countries invest in renewable energy sources on the basis of past investments and GDP. Also the technological efficiency affects the investment in renewable energy sources. The second part of the Table 2 shows the estimates for the countries that have nuclear generation plants. They base investment decisions in new renewable power plants on the past and, like non nuclear countries, they are conditioned by the level of production and technological efficiency. The share of nuclear energy generation shows also an inverse relationship. Probably, the continuous base load electricity ensured by nuclear power plants and the low greenhouse gas emission allow these countries to invest in additional renewable energy in a complementary way, in order to reach an optimal energy mix and to ensure the subsidies for investment in renewable energy. Stable in the samples appears the relationship between CO_2 emission and investments in renewable energy sources. In the samples, carbon dioxide emissions present a negative effect in promoting the renewable sources. The coefficient is negative and highly significant in both samples. The most reasonable interpretation is that countries produce electricity from more polluting sources, due to the need of supporting a sluggish economy which is more important than the environmental consequences of such type of production. The increase of CO_2 emissions portends an energy production system advanced but still tied to traditional sources that compress the dynamics of development of renewable sources. This result has been highlighted

in the literature (see e.g. Marques *et al.*, 2010). In both samples, Sargan test for over–identification fail to reject the null, so the model instruments are correctly identified. The estimates show that past investments in renewable energy sources have a significant influence on these current investments in both samples; in other words, there is a continuity of behavior in those countries that have shown sensitivity towards renewable energy sources. If it can have some statistical significance, this influence is stronger in the nuclear countries than to the other countries (non nuclear subsample).
Regarding industrial production technologies, factor analysis showed that the fast–growing countries tend to produce without particular attention to the environmental impact of production processes. Other countries traditionally stable in the high income cluster tend, instead, to show more attention to technologies with lower environmental impact and improved energy efficiency. In fact, from the results of the estimates in Table 2 we can observe the inverse relationship between CO_2 emissions and investments in renewable energy along with a direct relationship with energy intensity. On the other hand, the direct relationship with the level of national income shows that, reasonably, the resources needed for investment in renewable energy becomes available only after reaching a high enough gross domestic product.
Finally, the link between investment in renewable energy sources and power generation based on nuclear power plants shows an inverse relationship that is the signal of a different urgency of adjustment in countries with nuclear technology that have already cut CO_2 emissions. Thus, the presence of nuclear power plants depresses the trend of investment in renewable energy. This has been highlighted in the analysis in which a factor is the presence of economically advanced countries that strengthen their share of electricity from nuclear power. The econometric model that we have proposed reinforces the observation that sees a dynamic circular movement of countries behavior that is characterized:

- by growing countries moving toward greater income with less efficient technologies and less attention to the environmental issues,
- by higher income countries moving towards the use of a greater share of nuclear energy in their production mix, and
- from countries with income less relevant those have more attention to sustainability and moving towards the production from renewable energy sources.

The two methodologies used in this study are confirmed with each other, and each on their own account provides a secondary contribution to the understanding of the dynamic mechanism that has developed over almost thirty years in the energy planning.

5. Concluding remarks

This study analyzes the driving of investment in renewable energy sources in two samples. The former, in which are included the countries that base their electricity generation principally by fossil fuel while the latter includes the countries with nuclear power plants. In this paper we observe that energy policy is different in the two subsamples. In fact, in the first sample we observe the renewable sources alongside but not replacing the sources of production based on fossil fuel. The growing demand for energy, therefore,

is only partly offset by renewable energy sources. In fact, at this time, renewable energy sources do not guarantee continuity in the peak hours. Countries with nuclear power generation, instead, invest in renewable energy but they are dependent from the same nuclear generation that can reduce the environmental impact of growing energy demand by the population and businesses in the area. The countries in the sample preferred, in their developmental stages, the use of traditional energy sources, turning their attention to renewable and nuclear energy in the next stage of economic growth.
As usually happens in other studies, the models used address the issue of sustainability from a single point of view because the same modeling is more easily addressed by the side of measurability and availability of variables defined and measured over a sufficiently long time span. For this reason, in this study were not considered in the analysis, issues related to:

- safety and availability of energy supplies;
- volatility of fuel prices and their increase over time;
- management and treatment of nuclear wastes ;
- growth sustainability of the availability of raw materials.

A simpler approach, like that used in this paper is certainly valuable to understand some aspects of the issue. In this case, it appears that currently countries have to pursue an integration policy between the sources and process technologies for electricity generation. In spite of the different productive characteristics they have and without considering production costs (which are regarded as secondary, assuming the energy as a commodity whose demand is virtually inelastic) some authors (see e.g. Verbruggen, 2008) argue that the two technologies cannot have a common future in a perspective of sustainable energy. The countries, in energy planning, should work towards energy efficiency and renewable sources. The road to energy sustainability passes through the use of renewable resources that can complement the nuclear technology on condition that both exceed their own limits.

ACKNOWLEDGEMENTS

Authors have benefited from useful discussions with the participants of the 7^{th} Conference on Sustainable Development of Energy, Water and Environment Systems. They also acknowledge the editor and two anonymous reviewers for detailed comments and suggestions. The usual disclaimer applies.

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SUMMARY

Investments in renewable energy sources: the relationship with nuclear power consumptions

The aim of this study is to analyze the driving of investment in renewable energy sources in countries with, or without, nuclear power plants. To address these issues, a dynamic panel analysis of the renewable investment in a sample of 29 countries is proposed. Results demonstrate that investments in renewable sources present an inverse relationship with share of nuclear power generation in countries with nuclear power plants but in the countries with power generation based on fossil fuel, investments in renewable sources depend on GDP and technological efficiency. Results also show that energy sustainability passes through the use of renewable resources that can complement the nuclear technology on condition that both exceed their limits.

Keywords: Sustainable Energy; Factorial Analysis; Dynamic model; Renewable Energy Sources; Energy Planning