THE NEXUS AMONG RENEWABLE ENERGY, R&D ACTIVITIES AND GENDER INEQUALITY: EVIDENCE FROM EASTERN EUROPE

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Abstract: *The ecological transition process is of vital importance to modern economies. In the literature, little attention has been paid to the role that social factors can play in the diffusion of renewable energy. The paper aims to contribute to this debate by focusing on the connections between R&D activities, gender inequality and renewable energy. Specifically, many authors have underlined the positive influence that R&D activities can have on the ecological transition process, by favouring the diffusion of green innovations within the various economic sectors. On the other hand, some studies have shown that gender inequality can represent an obstacle towards the adoption of more sustainable consumption and production choices in the energy context. In our study we wanted to combine the two aspects: is it possible that a greater participation of women in R&D activities could have a positive impact on the diffusion of energy from renewable sources? To answer the question, we employ a panel vector autoregressive model in first differences to test complex dynamic relationships among renewable electricity production (as a proxy of the ecological transition), R&D expenditures (as a proxy for a country's innovative capacity), and share of female researchers (as a proxy for gender equality in the sector), controlling for per capita income. The study concerns 9 Eastern European countries for the period 2000-2019. The results show that the R&D expenditure is positively related to the production of electricity from renewable sources. Moreover, increased employment of women in R&D activities seems to support the ecological transition process. Finally, an increase in R&D spending seems to ensure easier access for women in the research sector. Supporting R&D activities, however, may not be enough, since women participation in those activities does not show a path dependence. Furthermore, from the impulse response analysis, a shock exerted on the share of female researchers produces positive effects on the diffusion of renewable energy, but only for a short period. Policymakers should make constant efforts to favour the participation of women in R&D activities: the global energy transformation needs to be inclusive and women have to be part of it.*

Keywords: *Renewable energy; R&D activities; Gender inequality; PVAR; Eastern European countries.*

JEL Classification: *Q56; J16.*

1. Introduction

The energy question has always been at the centre of the evolutionary history of countries, starting from the most remote times (such as the Industrial Revolution) up to the present day, due to its link with the environmental question. Energy has positive aspects, as it is essential for human life, for the production of consumer goods that are used daily, etc. (Al-Mulali and Normee Che Sab, 2013), but this does not remove the downside. Increasing energy consumption, as well as its production, has increasingly highlighted the limits of traditional energy sources (Sun et al., 2022; Anwar et al., 2021; Salem et al., 2021), other than an increase in greenhouse gas emissions (Bourcet, 2020). For these reasons it is necessary to decarbonise the economy through the increased use of renewable energy (RE) sources (Quan et al., 2021; Li et al., 2021).

To safeguard the environment, therefore, an energy transition towards alternative and ecological sources such as renewables is necessary. The expansion of RE guarantees energy security, reduction of production costs, diversification of energy consumption by decreasing the dependence on fossil fuels in production. Due to the importance of RE development, various studies are conducted on the its determinants (see Bourcet, 2020, for a systematic literature review).

The relationship between economic growth and RE has been studied over the past decade. Several studies have confirmed the conservation hypothesis, which implies a one-sided causality between economic growth and RE diffusion (Tiwari, 2011); other studies emphasize the bidirectional causality between RE diffusion and economic growth (Amri, 2017; Al-mulali et al., 2014; Eren et al., 2019).

Although the literature focuses mainly on the effects of economic growth, financial development and trade, other factors such as social aspects have not been adequately considered (Bourcet, 2000). Specifically, there is a notable lack of studies on the relation between RE ad R&D activities as human capital projection (uz Zaman et al., 2021), as well as on the impact that gender inequalities can have on the industry (Feenstra and Özerol, 2021).

R&D activities, due to their effects on CO_2 reduction, can help the economy move towards RE production (Chen and Lee, 2020; Li et al., 2020; Cheng et al., 2019). The development and diffusion of renewable energies require adequate technologies, which guarantee a competitive and efficient energy supply; this can be stimulated by human capital and knowledge deployment (Przychodzen and Przychodzen, 2020).

The literature is particularly lacking on the link that may exist between gender inequality and RE. Women can bring new viewpoints to the workplace and improve collaboration, thanks to their skills and sensitivity. Still, according to an IRENA survey (2017), women represent 32% of the fulltime employees in the sector; moreover, their participation in participation in science, technology, engineering and mathematics (STEM) jobs (28%) is much lower than in administrative jobs (45%).

Can gender inequality in R&D activities affect production from renewables?

We studied this link on a sample of EU transitional economies (Bayar et al., 2021), specifically in Eastern Europe. As a method of analysis, we used the Panel vector autoregression (PVAR) model, following the recent empirical literature (Charfeddine and Kahia, 2019; Lin and Zhu, 2017).

2. Empirical analysis

2.1. Methodology and model specification

The purpose of the analysis is to highlight the role of some determinants of the RE, and specifically gender equality in R&D activities, in a panel of 9 Eastern European countries (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovak Republic), using the longest time span possible from 2000 to 2019. Our empirical strategy is based on the PVAR approach, combining the traditional VAR, which treats all the variables in the system as endogenous, with the panel data approach, which borrows strength from the cross-sectional dimension and focuses on bidirectional effects. Following the literature, we have introduced a model based on the variables listed in Table 1.

Table 1: Data description and sources

Variable	**Definition**	**Source**
REN	Share of electricity production from renewables	Our World in Data
GDP	GDP per capita, PPP (constant 2017 international $)	World Bank
RAD	Research and development expenditure (% of GDP)	World Bank
WOM	Share of female researchers by sector of performance (Percentage based on full-time equivalents)	Eurostat

Following Love and Zicchino (2006), we introduced the specified PVAR model:

$$X_{it} = f_i + G(L)X_{it} + e_{it} \quad (1)$$

where X_{it} represents the vector of stationary variables in our analysis, f_i represents a vector of individual (country in our case) fixed effects, $G(L)X_{it}$ is a square matrix of polynomials in the lag operator, and e_{it} is the random error term (later, *d* denotes the first difference operator). The descriptive statistics for the variables are reported in Table 2.

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
REN	180	19.64	19.83	0.12	80.00
GDP	180	24388.10	6437.76	10503.62	40981.06
RAD	171	0.85	0.40	0.36	2.28
WOM	171	40.95	8.52	23.10	60.80

2.2. Empirical testing

Macroeconomic variables are usually characterized by non-stationarity, which can cause spurious results in the context of VAR and panel analyses. A possible solution is the use of the first-difference transformation. The first step of the empirical analysis is to check the stationarity of the various series using both first- and second-generation unit root tests. Specifically, two first-generation unit root tests (IPS and MW) and a second-generation unit root test (Pesaran) have been used. All tests are characterised by a null hypothesis that assumes a unit root. The results of these panel unit root tests are reported in Table 3 (variables in level) and Table 4 (variables in first differences).

Table 3: Unit root tests: variables in level

Variable	IPS W-t-bar	MW	Pesaran
REN	3.289	0.884	0.218
GDP	3.437	1.000	0.025**
RAD	1.885	0.925	0.109
WOM	-1.360***	0.446	0.517

Note: *p < 0.1; **p < 0.05; ***p < 0.01

Table 4: Unit root tests: variables in first differences

Variable	IPS W-t-bar	MW	Pesaran
dREN	-8.677***	120.922***	-4.485***
dGDP	-4.985***	55.186***	-0.618
dRAD	-7.434***	72.939***	-2.633***
dWOM	-10.479***	118***	-5.589***

Note: *p < 0.1; **p < 0.05; ***p < 0.01

The results show that not all the variables are stationary in levels. However, all the chosen variables are stationary after the first difference: all the series are integrated of order one (I(1)).
Table 5 shows the results of the cointegration tests introduced by Westerlund (2007). These tests assume the null hypothesis of no cointegration, which cannot be reject based on the results of all four tests. Therefore, the empirical characteristics of the chosen variables require estimation in first differences, as the variables in level are not cointegrated, as well as non-stationary.

Table 5: Cointegration tests

Statistic	Value	p-value
G_t	-2.039	0.220
G_a	-4.771	0.260
P_t	-4.087	0.820
P_a	-3.812	0.760

Note: p-value are robust critical values obtained through bootstrapping with 100 replications

We examined the correlation matrix and the variance inflation factor (VIF) to assess whether collinearity and multicollinearity were a concern for our analysis. The statistics are shown in Table 6 (dREN is used as dependent variable). Given the low correlation values and the low VIF and mean VIF values, we can conclude that collinearity and multicollinearity were not a concern.

Table 6: Correlation matrices and VIF statistics

	dREN	**dGDP**	**dRAD**	**dWOM**
dREN	1.00			
dGDP	-0.03	1.00		
dRAD	-0.08	0.03	1.00	
dWOM	0.04	-0.06	-0.09	1.00
VIF		1.00	1.01	1.01
mean VIF	1.01			

The final preliminary step is lag order selection. Following the econometric literature, the optimal lag length should minimize the moment model selection criteria developed by Andrews and Lu (2001): the moment Bayesian information criterion (MBIC), moment Akaike's information criterion (MAIC), and moment Hannan and Quinn information criterion (MQIC). Based on the three model selection criteria, a first order PVAR model is the chosen one (see Table 7).

Table 7: Lag order selection criteria

Lag	MBIC	MAIC	MQIC
1	-219.82	-57.05	-122.79
2	-168.13	-46.05	-95.36
3	-105.75	-24.36	-57.24
4	-58.26	-17.57	-34.01

We removed the deterministic fixed effects f_i in Eq. (1) by using the first difference transformation. As well known, this method may generate the so-called Nickell bias (1981) due to the correlation between the first-differenced lag and the first-differenced error term, which both depend on e_{it-1}. In this context, estimating the model using OLS will produce biased and inconsistent results (Baltagi, 2008). We use forward mean-differencing, also referred to as the Helmert transformation (Love and Zicchino, 2006; Arellano and Bover, 1995) to overcome this problem. The system may thus be estimated using the Generalized Method of Moments and the lagged values of regressors can be used as instruments.

2.3. Results

The first order PVAR results are shown in Table 8.

Table 8: PVAR results

		Dependent variables			
		dREN	**dGDP**	**dRAD**	**dWOM**
Lagged independent variables	**dREN**	0.377***	70.169***	-0.022***	-0.167***
	dGDP	0.000	0.408***	0.000**	0.000
	dRAD	3.998**	3423.896***	0.637***	1.213***
	dWOM	4.892***	-746.522***	-0.251***	-0.820***

Note: *p < 0.1; **p < 0.05; ***p < 0.01

The results show that GDP does not have a statistically significant impact on REN. In the literature this influence is often proved to be negative (Marra and Colantonio, 2021 and 2022; Sung and Park, 2018; Cadoret and Padovano, 2016; Omri and Nguyen, 2014; Salim and Rafiq, 2012). An increase in income is usually followed by an increase in energy consumption; in the past, this was mainly satisfied through traditional sources, while nowadays there is a greater use of renewable sources.

As expected, an increase in RAD generates an increase in REN. We can emphasize that we used generic R&D expenditure, since green innovation pervades every kind of sector. Moreover, RAD shows a positive incidence on GDP.

An increase in time spent by women (WOM) in R&D activities is usually followed by an increase in the production of energy from renewable sources (REN), used as a proxy for the ecological transition process. In other words, women’s participation in STEM jobs allows their talents and sensibility to be fully utilised and it can represent a boost for sustainable development.

An increase in REN usually implies an increase in GDP, that is a greater production of energy from renewable sources does not represent an obstacle to economic growth.

Interestingly, an increase in R&D spending allows women to spend more time on those activities.

Finally, observing the main diagonal, all the variables show a path dependence, with the exception of WOM.

The stability of the PVAR model was analysed and verified as the eigenvalues are strictly less than 1 (see Table 9). Moreover, the test of overidentifying restriction (Hansen’s J chi2) is equal to 72.25 (p = 0.224): this confirms the goodness of the model, since the null hypothesis that the over-identifying restrictions are valid is verified (the included instrumental variables are valid instruments and uncorrelated with the error term, while those instruments not included are properly excluded).

Table 9: Eigenvalue stability condition

Real	Imaginary	Modulus
-0.159	-0.860	0.874
-0.159	0.860	0.874
0.460	-0.401	0.610
0.460	0.401	0.610

We also executed the Granger causality test, which is based on the Wald test. Specifically, the blocks of exogeneity analysis (ALL) confirmed the existence of endogeneity (see Table 10).

Table 10: Granger causality test

Equation Variable	Excluded Variables	Chi2	p value
dREN	dGDP	0.512	0.474
	dRAD	4.782	0.029
	dWOM	95.360	0.000
	ALL	107.936	0.000
dGDP	dREN	9.776	0.002
	dRAD	24.371	0.000
	dWOM	60.031	0.000
	ALL	119.483	0.000
dRAD	dREN	13.553	0.000
	dGDP	5.427	0.020
	dWOM	102.040	0.000
	ALL	135.121	0.000
dWOM	dREN	105.086	0.000
	dGDP	0.373	0.542
	dRAD	9.096	0.003
	ALL	131.207	0.000

Table 11 reports the variance decomposition, which assesses the relative weight of shocks in one variable to variation in other variables over time. The forecast error variance decomposition follows the Cholesky decomposition and was performed using 1000 Monte Carlo simulations for 10 periods. The table shows that each variable is mainly influenced by its lag. Particularly, REN is mainly determined by WOM (31.78%) on average during a 10-year period.

Table 11: Variance decomposition analysis

		Impulse Variable			
		dREN	**dGDP**	**dRAD**	**dWOM**
Response variable	**dREN**	62.35%	0.52%	5.35%	31.78%
	dGDP	17.14%	54.20%	11.13%	17.53%
	dRAD	47.93%	4.44%	16.19%	31.43%
	dWOM	40.99%	0.51%	5.20%	53.29%

Note: Variation in response variable explained by the impulse variables in the columns (10 periods ahead)

The impulse response functions (see Figure 1) illustrate the reaction of one variable in the system to shocks in another variable, while keeping all other shocks equal to zero (a Gaussian approximation based on 200 Monte Carlo simulation was employed to estimate the impulse response functions, which in this case also followed the Cholesky decomposition). When one positive unit shock is exerted on one variable in the current period, the response variable usually exhibits a remarkable response in the early phases, followed by a slight fluctuation thereafter. Specifically, positive shocks exerted on WOM generate a significant response in REN during the early periods.

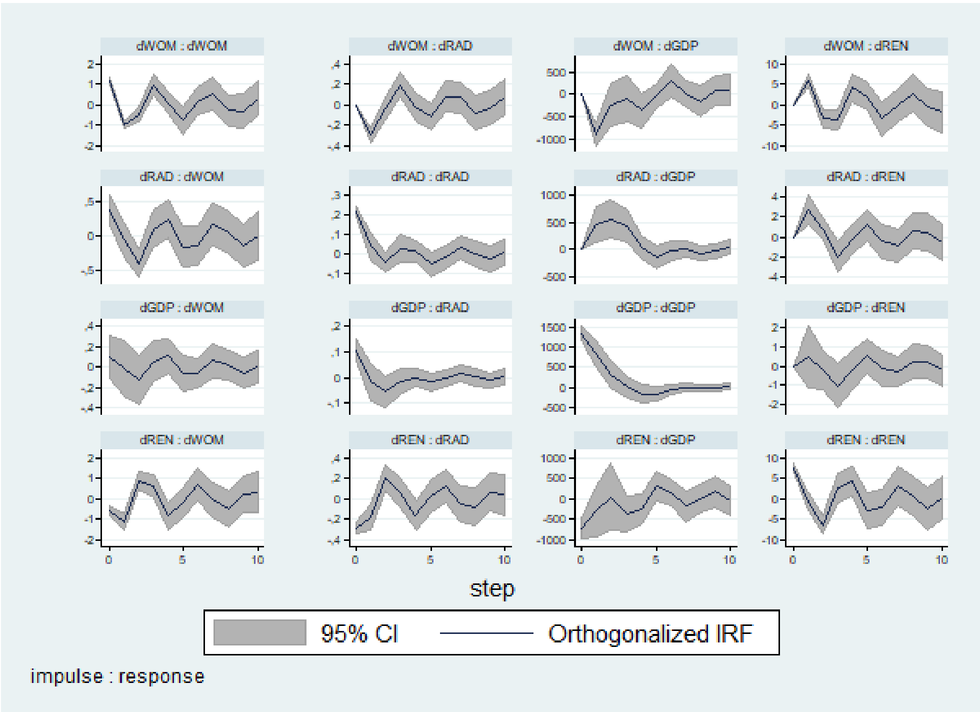

Figure 1: Impulse Response Analysis

Conclusions and Policy Implications

Little attention has been paid to the role that social factors can play in the ecological transition process (Bourcet, 2020). This paper contributes to the debate by considering the link among R&D activities, gender inequality and the production of energy from renewable sources, for a group of Eastern European countries in the period 2000-2019.

The results of the analysis (based on a PVAR model) highlighted some interesting relationships over time:

1. as expected, the R&D expenditure is positively related to the production of energy from renewable sources (nowadays almost all sectors, from logistics, to construction, agri-food, packaging, etc. are interested in green innovation);
2. increased employment of women in R&D activities seems to support the ecological transition process;
3. an increase in R&D spending seems to ensure easier access for women in the research sector.

Supporting R&D activities, however, may not be enough!

WOM, which from the variance decomposition analysis seems to have a relevant weight on REN variation, does not show a path dependence. Furthermore, from the impulse response analysis, a shock exerted on WOM produces positive effects on REN, but only for a short period. Policymakers should therefore support "gender equality" in R&D activities over time, for example through scholarships, grants, fiscal and financial facilities, etc. to have a greater chance of success on the road to a more sustainable development.

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