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The Causal Nexus between Income and Energy Poverty in EU Member States

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Abstract: This paper investigates the presence of a causal relationship between energy poverty and income poverty in the EU Member States through a Panel Vector Autoregressive specification, and controlled with a set of explanatory variables collected from the Eurostat energy database and the OECD environment database for 2007–2018. Deepening the nexus between energy poverty and income poverty is a relevant issue for tailoring policies to tackle poverty and improve the well-being of citizens, supporting the policy makers in the allocation of planned funds provided by the Recovery plan, "Next Generation EU". The results of the panel VAR model estimation and Dumitrescu and Hurlin test suggest that there will be no change in the long-run equilibrium when income poverty remains constant. Moreover, the reduction in energy poverty is expected to have a positive effect in terms of overall economic poverty reduction. Finally, there is evidence that substituting fossil fuels with renewables helps to reduce energy poverty and widespread poverty due to the leverage effect on economic development as well as to support the achievement of some of the 17 Sustainable Development Goals addressed by United Nations.

Keywords: energy poverty; income poverty; EU member states; PVAR model; GMM estimator; panel causality test

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1. Introduction

The issue of income poverty and energy poverty are becoming a flourishing research stream increasingly investigated by scientific literature. Nevertheless, even though the concept of income poverty (hereafter IP) has been shared among researchers, the notion of energy poverty (hereafter EP) has not yet been unambiguously defined. This indeterminacy affects the effectiveness of policies aimed at tackling EP itself.

One of the first definitions considered EP as "an insufficient access to modern energy sources, such as electricity and natural gas" [1]; that is, a deprivation of well-being and the consequent inability to meet the basic needs of an individual or family. However, EP cannot be simply be equated to fuel poverty, being the last thing commonly referred to by households suffering from insufficient monetary resources to pay for their basic energy needs [2,3]. In addition, according to the latest statements of researchers, EP also should embrace both the cooling needs of people, as the climatic temperature is expected to increase in the coming years due to global warming (e.g., [4]), and the daily mobility needs for access to basic services and participation in social life (e.g., [5]).

As pointed out by [6], EP is a concept somewhat closer linked and dependent on IP. Following the Eurostat definition, a country's IP is measured with the risk-of-poverty rate.

Although IP and EP may seem similar, as both take into account conditions of poverty that may be due to a condition of economic deprivation, and many low-income households are also energy poor, it is commonly accepted that EP does not fully overlap with IP [4,7].

Over the years, many methods and indicators to measure EP have been proposed, but the outcomes of investigations have often led to wide discrepancies for the same country or adjacent areas depending on the methods applied. The indices of EP also vary significantly according to the characteristics of families (composition and size), the demographics of the regions and the habits of the population [8–10]. Additionally, disparities in technological and economic conditions under which EP assessments are conducted and the high variability in the quantification of vulnerable consumers lead to anomalous results, and to the emergence of relevant disparities among regions depending on energy sources and consumers' behaviours [2,3,11]. Consequently, it is hard to carry out comparative analyses, and a lack of structured spatial-temporal datasets emerges [12].

Because it is so difficult to understand a complex phenomenon such as EP using current databases and one-dimensional indicators, scholars are looking for a standard technique to analyse EP that includes the quantification of characteristics that are distinctive to the locations being studied.

As a result, EP becomes a notion that must be qualified in light of the setting, its environmental conditions, and socioeconomic characteristics [13,14]. Specifically, researchers recommend the inclusion of local and regional features in developing a uniform methodology to assess EP across the investigated economies [7,15].

The fragmentation of the legislation adopted in each country is a consequence of the complexity of taking into consideration numerous and different local specific factors for identifying the EP, and at the same time, the main reason that explains the absence of a harmonized system of European policies to tackle the EP [16].

It is not surprising that, while all countries have included vulnerable consumers in their regulatory framework, only five countries (United Kingdom, France, Slovakia, Ireland, and Cyprus) have legislated EP [17] (Dobbins et al., 2019).

The current increase in energy prices will lead to an erosion of disposable household income and will have as a further negative consequence, being the increase in the share of energy-poor families. These bleak prospects necessitate the immediate implementation of coordinated efforts aimed at reducing the proportion of households living in both IP and EP. With this in mind, this paper aims to study the existence of a causal nexus between IP and EP within the European Nation-Member States (EU-MS). The investigation of the presence of a causal nexus between IP and EP can help decision makers address the policy action aimed to eradicate the two conditions of deprivation. The outcomes about the possible existence of a causal nexus between IP and EP are an important prerequisite for the design of policies able to improve the standard of living and well-being of citizens. Due to the significant heterogeneity of the national legislative frameworks and the lack of a consistent interpretative framework to channel and tackle this issue, policies have not been sufficiently effective in reducing the vulnerability of individuals and families living in IP and/or EP. Furthermore, given the indeterminacy of the reference framework, there is also the risk that some interventions may cause counterproductive effects by widening the EP, such as the so-called carbon tax [18]. Therefore, tailored and targeted actions are nowadays required (e.g., [17]).

To reach this aim, a panel dataset of 26 EU-MS for the years 2007 to 2018 is used. Data is obtained from the group of 28 EU countries (pre-Brexit), we excluded Malta and Cyprus for which not all data were available. The UK is included because it was still a member of the European Union in 2018. Data includes variables extracted from the Eurostat Energy Database and the OECD Environment Database at the national level. Both databases are public and available for consulting. Eurostat Energy Database, to the link: https://ec.europa.eu/eurostat/web/energy/data/database (accessed on 8 December 2021), while OECD Environment Database, to the: https://stats.oecd.org/ (accessed on 8 December 2021).

The search of a causal nexus is not a novelty in economic literature. For instance, the nexus between energy consumption and economic growth (e.g., [19–22]), economic growth and inflation (e.g., [23]), remittances and poverty (e.g., [24]), food, water and energy (e.g., [25]) have been already surveyed. Anyway, to the best of our knowledge, the causal link between IP and EP has not been previously studied. Few scholars have investigated the correlation between EP and IP, with particular emphasis on England (e.g., [14,25]).

The remaining of the paper is structured as follows. Section 2 presents the framework, while Section 3 describes the data and method. Section 4 discusses the empirical strategy and the findings; Section 5 reports the policy implications. The last section includes conclusions.

2. Theoretical Framework and Hypotheses

EU Statistics on Income and Living Conditions (EU-SILC) survey collects timely and comparable cross-sectional and longitudinal multidimensional microdata on income, poverty, social exclusion and living conditions. Among the large amount of data collected by the EU-SILC survey to monitor the progresses of EU-MS towards the reduction in poverty in all its forms, Eurostat quantifies the percentage of households who are unable to keep their dwelling adequately warm (*enpov*). This indicator is commonly used in research on EP. Starting from the pioneered approach by [26] Healy and Clinch (2004), the first fully comparative study of EP across the EU, *enpov* has often been used as a primary indicator capturing the various aspects of EP [27]. It represents the outcome variable, both in studies that investigate the phenomenon with regard to specific countries [28], and in those focusing on the effects of EU energy policies on the EP [29]. For these reasons, we adopt *enpov* as proxy for EP.

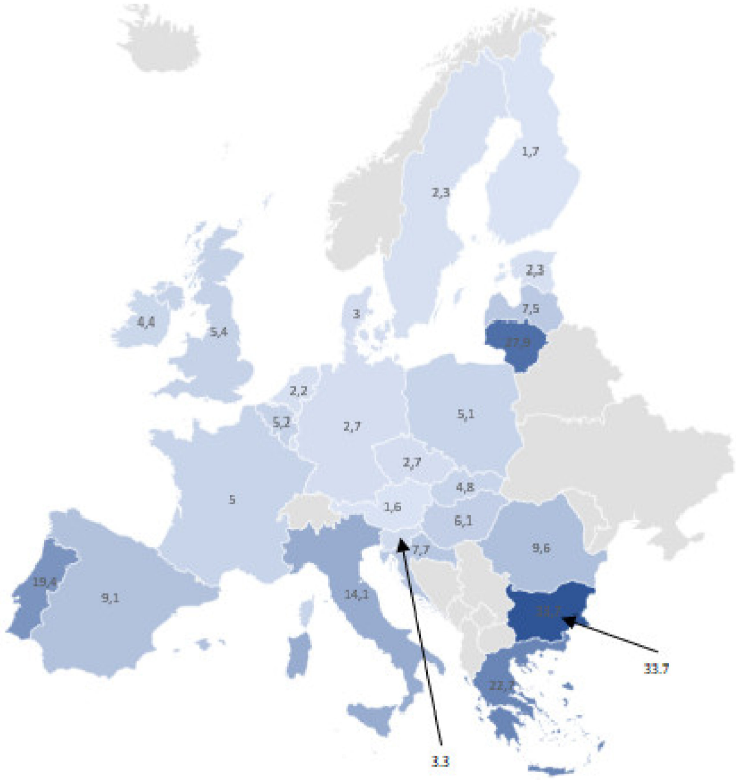
Eurostat calculates the share of persons at risk of poverty or social exclusion (pov) as a measure of the IP, using data from the EU-SILC survey.

This being the proportion of people who are either at risk of becoming poor, are severely materially deprived, or live in a home with a very low work intensity, and the sum of total population.

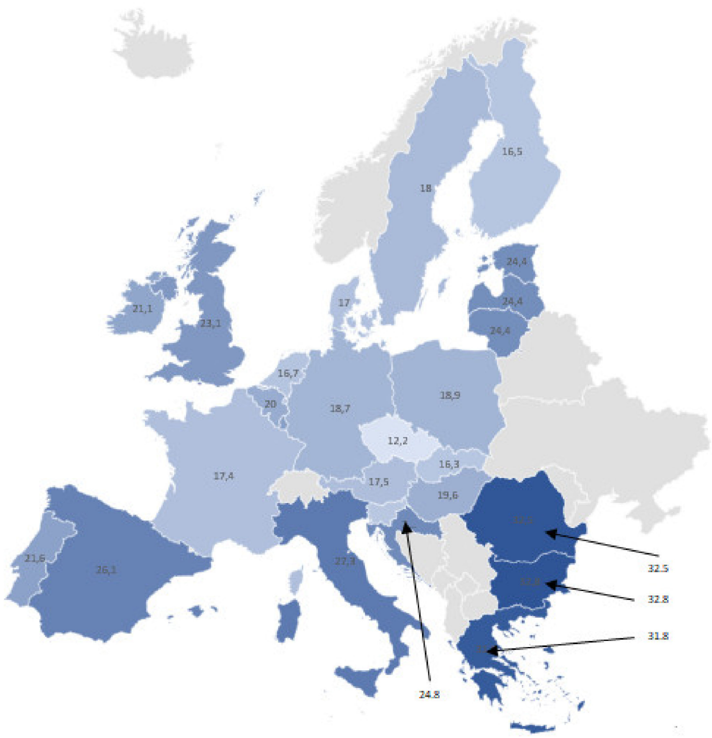
Figure 1 reports the 2018 spatial distribution of the *EP* (Figure 1a) and *IP* (Figure 1b) indicators as calculated by Eurostat. Focusing on EP (Figure 1a), a clear disparity between the countries of north-western Europe and those of the south-east emerges. Focusing on IP distribution, we observe that the differences between countries are less evident; moreover, the spread between the shares of households in IP are much greater than those in EP.

The EP distribution reflects the traditional gap between high-income and low-income EU-MS. Nowadays, EP is believed to affect about 11% of the EU population [30], while those at-risk-of-poverty are about 17% of EU inhabitants [31].

In general, both IP and EP can be assumed to decrease but as household income increases. The pattern may differ according to income decile and geographical area. In some countries, the gap between food and non-food spending (including energy) and EP is large and substantial while in other countries this gap is less evident. The association between IP and EP depends on the level of access to modern energy sources and the efficient use of traditional ones. In some countries, where households have reliable access to modern energy services, EP closely follows spending or IP. In others, where households are relatively poor with limited access to modern energy services, EP is higher than IP. An increase in EP rates is also expected due to higher energy prices, lower net incomes and poor energy efficiency of housing. Not by chance, in the last decade electricity prices have skyrocketed in most countries. This rise, combined with the recent economic and financial crisis, and the poor energy performance of the EU housing stock, has increased concerns about EP in EU-MS. Unemployed are the most vulnerable group: almost half (48.6%) of them living in EU-MS were at risk of poverty in 2018. So, both IP and EP are crucial challenges for society, and the issues noted are of extreme importance.



(**a**)



(**b**)

Figure 1. (**a**) 2018 Energy poverty indicator distribution (%); (**b**) 2018 Income poverty indicator distribution (%).

For these reasons, in this paper, we analyse the causal nexus between EP and IP. As already specified, although the idea of an association between EP and IP is shared in literature [14,24], no previous surveys have specifically investigated this casual nexus.

Searching for the causal nexus between the two mentioned indicators, led us to the formulation of four hypotheses trying to explain the cause-and-effect relationship:

1. "Deprivation" hypothesis. With this definition, we refer to the possibility that EP affects the risk of IP both directly and indirectly as a complement of dwelling characteristics. The presence of a unidirectional relationship from EP to IP would confirm the deprivation hypothesis. The expenses necessary to make a house comfortable (not hot in summer and not cold in winter) lead to a substantial reduction in disposable income that can make a family not at risk of poverty, pass into those at risk. In this case, policies to support households in conditions of EP would also have merit in tackling IP.
2. "Preservation" hypothesis. This suggests that IP has a negative impact on EP. This condition occurs when households in IP are also those in EP. The lack of economic resources needed to meet essential needs also leads to a reduction in the budget available to make the home liveable. In this case, policies designed to reduce EP can have a negative impact on IP. The idea of preservation is supported if there is a unidirectional relationship from IP to EP.
3. "Feedback" hypothesis. Here we argue the presence of a bidirectional causal relationship, in which is emphasized the interdependent relationship between the two conditions. In this case, the political actions will have to take into account both deprivation conditions, creating a synergy. Policy makers must be aware that actions designed to counter one of the two conditions will also have beneficial effects on the other. It is no longer necessary to think of two different areas, but they should be integrated into a single framework.
4. "Neutrality" hypothesis. This considers EP to be a small component of the IP and, thus, may have little or no impact on this indicator. In this case, we observe the absence of a causal relationship between the variables considered. Hence, the policies should be separated and different, depending on the type of poverty that is to be tackled.

Hence, the identification of the causal nexus may provide useful guidance for action to be taken, as part of an EU action aimed at tackling inequalities and compliance with the UN Sustainable Development Goals It becomes even more relevant in the light of the new green deal that the EU (Directive 2019/944) has taken and on which EU-MS seem to converge on the use of the so-called "Next Generation EU" following the recent pandemic wave.

3. Data and Methods

Data and Descriptive Statistics

The search of the causal link between IP and EP is the key for testing and interpreting the four research hypotheses listed above. Since EP and IP are influenced by other factors, various exogenous variables have to be included in model specifications. In this section, we describe the variables selected for this purpose and the motivations that led us for their selection.

As suggested by [32], the combination of high prices and low GDP (*gdp*) are the main drivers of both EP and IP. For this reason, we consider the annual rate of change in electricity prices for non-household consumers (Δ_*elprice*), the gas prices for household consumers (*gprice*), and the GDP in PPP (*gdp*). To avoid the risk of collinearity between the gas and electricity price for households, it was preferred to take the price of energy for the non-household consumers. The idea is that Δ_*elprice* has an indirect effect on households, because firms generally transfer the extra costs resulting from fare increases to consumer prices [33]. These variables have been included among the exogenous economic factors.

According to some of the recent studies (e.g., [34]), effective EP eradication policies should necessitate an increase in final energy generation, as well as a reduction in the greenhouse gas emissions (*ghg*) as a means to reduce climate change direct impacts on the

EP [35]. Both these strategies would not be the same across countries but would require greater energy green generation efforts for the lower income countries while, for the higher income countries, the response could be the achievement of higher efficiency standards.

To assess whether these theoretical implications are empirically demonstrated in the panel of nations studied in this work, we looked at both variables measuring energy generation differentiated between fossil (*fos*) and renewable (*ren*) sources, and variables related to the level of energy efficiency (*ei*). Considering both the renewable and fossil components of energy generation can help to better understand to what extent one of the two has a greater effect in terms of reducing the two kinds of poverty.

There is an increasing literature on the distributional impacts of energy taxes (an exhaustive overview is provided in a paper by [36]. Recently, [37] pointed out the negative impact of environmental taxes on renewable energy investments in the EU-MS. Considering that penalizing investments also leads to a drop in income, we want to assess the effects of the perceived environmental tax burden (*envrev*) on the EP in terms of the redistributive effects on the income.

The domestic energy deprivation and/or energy vulnerability represent a global problem accentuated in Europe due to the recent economic downturns linked to both the 2008 financial crisis and the current COVID-19 pandemic [3], as well as the current rise in energy prices. Comfort, health and wellbeing in the house are considered among the most useful indicators to understand the EP situation beyond its traditional definition [38]. Following this research stream, we include in the explanatory variables, three EU-SILC indicators, measured at the country level: (i) the housing deprivation rate (*h_dep*), which is a measure of poor amenities and is calculated by referring to those households with a leaking roof, no bath/shower and no indoor toilet, or a dwelling considered too dark; (ii) the percentage of the population that claims to have costs related to housekeeping of more than 40% (*h_cost*), which gives an indication of the financial pressure that households face due to housing costs; and (iii) the share of the total population who have stated that they are in the state of arrears on utility bills (*arrears*).

Since the scientific literature shows how climate issues are linked to the EP, it has been decided to use two Eurostat indicators to sum up climatic characteristics of the countries: cooling and heating degree days by country (*cool_dd* and *heat_dd*). Heating degree day index is a weather-based technical index designed to describe the need for the heating energy requirements of buildings. *Cool_dd* describes the need for the cooling (air-conditioning) requirements of buildings; *heat_dd* describes the need for the heating energy requirements of buildings. They are derived from meteorological observations of air temperature, interpolated to regular grids at 25 km resolution for Europe. Metadata and technical issues relating to the development of the index are available at: https://ec.europa.eu/eurostat/cache/metadata/en/nrg_chdd_esms.htm (accessed on 8 December 2021).

A synthetic description and the data sources of the variables included in the analysis is reported in Table 1, while the main descriptive statistics and stationarity tests are listed in Table 2. In particular, the last two columns of Table 2 report the *p*-values both of the [39] panel unit root test and the Pesaran panel unit root test in the presence of cross-section dependence (CIPS) [40]. The latter test checks the presence of the unit root under the hypothesis of cross-sectional dependence in the data, avoiding possible spurious results of the traditional Levine test whose assumption is the cross-sectional independence across units.

Results show that, with the only exception being *envrev*, which was not stationary for the CIPS test, we failed to accept the null hypothesis of the unit root in the variables considered. We discarded the presence of time trends that can affect, with bias effects, the estimates.

The strong heterogeneity between countries shown in the descriptive analysis suggest using a proper model that takes into account this issue and the implications to explain it. We will consider the role of the exogenous variables and also that of the K lags of endogenous variables. Moreover, we will provide some assumptions about the obtained results.

Table 1. Variables Description.

Variable	Description	Source
Enpov	Percentage of households who are unable to keep their dwelling adequately warm—EU-SILC survey.	*Eurostat*
Pov	Share of people at risk of poverty or social exclusion—EU-SILC survey.	*Eurostat*
Δ_elprice	Annual rate of change in electricity prices for non-household consumers (EUR/kWh).	*Eurostat*
Gprice	Gas prices for household consumers (EUR/kWh).	*Eurostat*
Gdp	Gross domestic product at market prices (chain linked volumes 2010 = 100).	*Eurostat*
Fos	Per capita gross electricity production by fossil sources (thousand tonnes of oil equivalent).	*Eurostat*
Ren	Share of primary production of energy from renewable sources on total energy production (excluding hydroelectric generation).	*Eurostat*
Ghg	Greenhouse gases (million tonnes of oil equivalent).	*Eurostat*
Ei	Units (millions) of energy per unit of GDP (millions of euros chain linked volumes).	*Eurostat*
Envrev	Ratio between environmental tax revenues on total tax revenues.	*OECD*
H_dep	Percentage of the population deprived of each available housing deprivation items—EU-SILC survey.	*Eurostat*
H_cost	Percentage of the population living in a household where total housing costs (net of housing allowances) represent more than 40% of the total disposable household income—EU-SILC survey.	*Eurostat*
Arrears	Percentage of persons from the total population who are in the state of arrears on utility bills—EU-SILC survey.	*Eurostat*
Cool_dd	Weather-based technical index designed to describe the need for the cooling (air-conditioning) requirements of buildings.	*Eurostat*
Heat_dd	Weather-based technical index designed to describe the need for the heating energy requirements of buildings.	*Eurostat*

The basic panel specification of a fixed effect model is the following:

$$y_{it} = \mu_i + \boldsymbol{\Gamma} \boldsymbol{z}_{it} + \varepsilon_{it} \tag{1}$$

where y_{it} is the dependent variable for the i cross-sectional country at time t, μ_i represents the fixed unobserved individual (country) effects, and $\boldsymbol{z}_{it}$ is the vector of predetermined exogenous variables is the basic specification when cross sectional methods appear to be inadequate due to the longitudinal structure of the phenomenon analysed. However, in this setting the classical econometrics issues of (non-) bidirectional causality between time series also arises. To avoid this occurring, we introduce the extended vector panel specification (PVAR), which assessed the presence of a bidirectional causal relationship between them through proper econometric tools.

For this reason, we implemented a procedure developed by Dumitrescu and Hurlin [41] in order to test for Granger causality in panel datasets. It is an extension of the methodology provided by Granger [42] in which the underlying regression is written as follows:

$$y_{it} = \mu_i + \sum_{k=1}^{K} \alpha_{ik} y_{it-k} + \sum_{k=1}^{K} \beta_{ik} x_{it-k} + \varepsilon_{it} \tag{2}$$

where x_{it} and y_{it} are the observations of the two stationary indicators (IP and EP) for *i*-country (*i* = 1, . . . , N) at time *t*. Coefficients are allowed to differ across countries but are assumed time-invariant. The lag order *K* is assumed to be identical for all *i* and the panel must be balanced. The test assumes there can be causality if the null hypothesis that β_{ik} is equal to 0 for all the countries cannot be accepted. The PVAR specification is:

$$y_{it} = \mu_i + \sum_{k=1}^{K} \mathbf{A}_k \boldsymbol{y}_{it-k} + \boldsymbol{Bx}_{it} + \boldsymbol{Cz}_{it} + \varepsilon_{it} \tag{3}$$

Table 2. Summary Statistics.

					Panel Unit Root (*p*-Values)	
Variable	**Min.**	**Max.**	**Mean**	**Std. Variation**	**Levine**	**CIPS**
Enpov	0.300	67.400	10.643	11.523	<0.01	<0.01
Pov	12.200	60.700	23.726	7.567	<0.01	<0.01
Δ_*elprice*	−0.040	0.240	0.015	0.041	<0.01	0.023
Gprice	0.000	0.100	0.051	0.018	<0.01	<0.01
Gdp	81.500	168.000	105.976	10.402	<0.01	<0.01
Fos	0.000	0.451	0.111	0.107	<0.01	<0.01
Ren	0.020	0.930	0.327	0.242	<0.01	0.055
Ghg	11,507	1,001,192	180,991	228,317	<0.01	<0.01
Ei	54.700	552.860	184.145	90.262	<0.01	0.040
Envrev	4.590	13.130	7.602	1.825	<0.01	>0.1
H_dep	0.500	32.000	6.611	6.416	<0.01	0.023
H_cost	13.600	42.500	21.405	5.479	<0.01	<0.01
Arrears	0.000	42.200	10.850	8.972	<0.01	<0.01
Cool_dd	0.000	448.680	72.898	96.584	<0.01	<0.01
Heat_dd	0.000	6179.750	2877.117	1143.890	<0.01	<0.01

This is a vector specification of the Equation (1), in which $\boldsymbol{y}$ is an $m \times 1$ vector of endogenous variables for the ith cross-sectional; $\boldsymbol{y_{t-k}}$ is an $m \times 1$ vector of lagged endogenous variables. Let $\boldsymbol{x}_{it}$ a vector of predetermined variables that are potentially correlated with past errors. Let $\boldsymbol{z}_{it}$ n $n \times 1$ vector of strictly exogenous variables that neither depend on ε_t nor on ε_{t-s} for s = 1, . . . ,T. Moreover, the disturbances ε_{it} are independently and identically distributed (i.i.d.) for all i and t with E[ε_{it}] = 0 and Var[ε_{it}] = is a positive semidefinite matrix. We assume that all unit roots of **A** in Equation (3) fall inside the unit circle to assure covariance stationarity. In this specification, we assume parameter homogeneity for **A**, **B** and **C** for all *i*. A PVAR model is hence a combination of a single equation dynamic panel model (DPM) and a vector autoregressive model (VAR).

This approach is an extension of the traditional VAR approach with exogenous variables to a panel data. It allows to control for cross-country heterogeneity through the fixed individual effects, and assumes that the shocks to IP and EP (at time $t - k$) can transmit through the dependent endogenous variables. Since the dependent variables and the exogenous regressors are stationary (Table 2), this specification proposes to generate impulse response functions (IRFs) that take the intensity and the length of simultaneous reactions of the dependent variables by overriding all other shocks.

4. Results and Diagnostics

4.1. Results

The coefficients of the Equation (3) were estimated using the first difference GMM estimator on the forward orthogonal transformed variables. They were set up as instruments for the endogenous variables to avoid the correlation with the unobserved country-level fixed effect. The optimal lag order *K* was chosen using the Schwarz information criterion (BIC) according with the [43] model selection procedure. All the eigenvalues lie inside the unit circle and, consequently, PVAR satisfies stability condition.

These model diagnostics and the baseline results are reported in Table 3. An important feature of the PVAR is that the results can be analysed by treating all the target variables in the system as endogenous.

Table 3. GMM Estimates (standard errors in parenthesis).

	Enpov	Pov
Enpov $(t-1)$	0.0111 *** *(0.002)*	0.006 * *(0.003)*
Pov$(t-1)$	0.009 *** *(0.002)*	0.008 *** *(0.002)*
Δ_*elprice*	0.001 ** *(0.000)*	−0.001 *** *(0.000)*
Gprice	0.001 *** *(0.000)*	0.001 *** *(0.000)*
Gdp	−0.060 *** *(0.013)*	−0.039 *** *(0.010)*
Ren	−0.001 ** *(0.000)*	−0.000 *(0.000)*
Fos	0.001 *** *(0.000)*	0.001 *** *(0.000)*
Ei	0.103 ** *(0.022)*	0.043 *(0.028)*
Ghg	−0.001 ** *(0.000)*	−0.001 *** *(0.000)*
Envrev	0.001 *(0.001)*	0.001 *(0.001)*
H_dep	0.009 *** *(0.002)*	0.004 *(0.003)*
H_costs	0.006 *** *(0.001)*	0.007 *** *(0.001)*
Heat_dd	−0.002 *(0.001)*	−0.002 *(0.001)*
Cool_dd	−0.010 *(0.008)*	−0.012 * *(0.006)*
Arrears	0.011 *** *(0.003)*	0.014 *** *(0.003)*
Eigenvalues	0.017 0.002	
Dumitrescu and Hurlin Causality Test: *EP→IP*	Z-bar 5.740 ***	Z-bar tilde 2.573 **
Dumitrescu and Hurlin Causality Test: *IP→EP*	Z-bar 7.578 ***	Z-bar tilde 3.615 ***

*** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05.

The results of the Dumitrescu and Hurlin (DH) causality test reveal the existence of bidirectional causality. Both the two different statistics recommended for fixed T samples [44] lead us to reject the null hypothesis of absence of causality for all the countries in the panel, and to accept the alternative of causality at least for some of them. Based on this outcome, the suitability to introduce a vector panel specification is confirmed, which assesses the presence of a causal relationship between the two variables.

Results reveal that both IP and EP are directly related: reducing IP can also reduce EP and vice versa, as argued in the feedback hypothesis. This is an expected result confirming the theoretical hypothesis underlying this study concerning the causal nexus between the two concepts of poverty.

To quantify the strength of relationship between IP and EP, we use the generalized IRFs (Figure 2) with a bootstrapped 95% confidence interval. IRFs come into the light, as the direct effects of IP on EP are higher than the inverse one, EP on IP, and that for both the indicators there is time persistence. The EP can be considered as an aspect of IP and more often it may happen that the first includes the second, while less often the opposite case emerges.

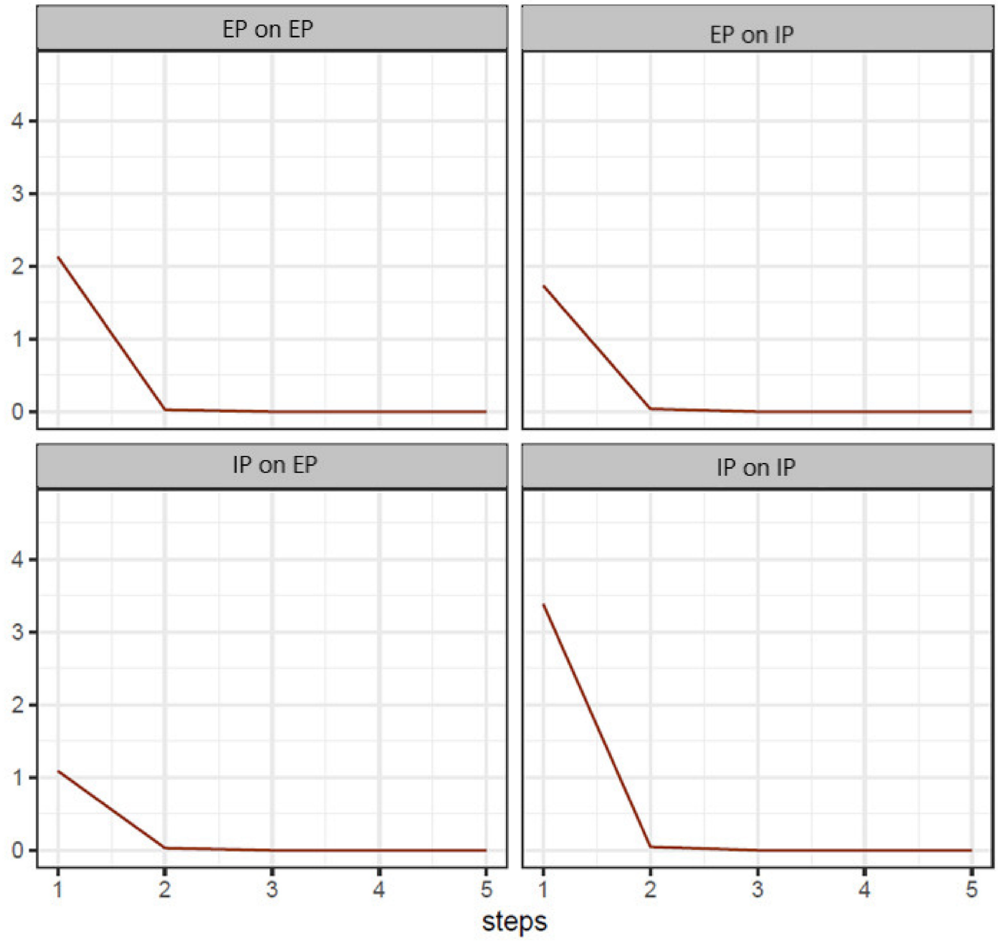


Figure 2. Impulse response functions of PVAR model with 95% confidence interval.

These particular functions synthesize the response of a variable over time in reaction to a shock that occurred in all the other endogenous variables of the system. A shock in a variable, in fact, is also transmitted to the other endogenous components of the model. Consequently, if a variable reacts to the shock of another one, it cannot be considered exogenous for the system.

It is important to note that in our case, there is a response between the two variables (confirming endogeneity) with an effect that is absorbed gradually over time (Figure 2). However, the absence of explosive responses to a shock reflects the stability of the estimated model. Moreover, IP is the least affected by variations assuming, therefore, a linear leading effect in the system. This means that if IP remains at steady state, there will be no change in the long-term equilibrium and any effect on EP will only be temporary. Energy prices (gas and electricity) have a direct influence on the EP trend. It has already been proved that in European countries, rising energy prices are associated with increasing energy poverty [45]. However, for electricity prices, this relationship is not confirmed with reference to the condition of IP. This is the only case in which the estimates of the model give conflicting signs. In high income countries, the poverty, in all its forms, is less widespread.

An interesting result concerns the composition of the baskets of the energy generation sources: the estimated coefficients of *ren* and *fos* present opposite signs. They indicate that the replacement of a generation from fossil sources with renewable sources, giving a leverage effect for economic development [46], also helps to reduce EP. This creates a synergy between the research to reduce both EP and the environmental impacts of energy production.

The analysis brought out a U-shaped relationship between energy intensity and income: it is positive if modern energy sources dominate the traditional ones and negative if vice versa [47]. The significant and positive coefficient of the variable *ei* of the first equation of the model means that EU-MS fall in the decreasing branch of the U-shaped relationship: the lower the income, the higher the energy intensity. It occurs because in these countries there is a still prevalence of traditional energy sources. EU-MS are less exposed to the economic impacts of climate change and have a low degree of environmental vulnerability [48]. Hence, the use of technologies and infrastructures with a high level of emissions (but cheaper) still represents an attractive opportunity from them, responding to development and job creation needs. For this reason, a negative and significant relationship between the coefficient of greenhouse gas emissions (*ghg*) and the two dependent variables of the two model equations emerges. Moreover, since there is not yet a real necessity to tailor infrastructure toward pollutant emission reduction models, the coefficient of the variable of policies supporting renewable energy (*envrev*) is not significant in terms of poverty reduction in both equations.

Focusing on comfort, health and wellbeing of the houses, we find that the housing deprivation rate (*h_dep*) is significant only in the relationship with EP as outcome, while the percentage of the population that claims to have costs related to housekeeping of more than 40% (*h_cost*) and the share of the total population who has stated that are in the state of arrears on utility bills (*arrears*) present a positive and significant relationship with both outcomes. This confirms that the costs associated with housing have a significant impact on the economic and energy hardship of the population.

The low environmental vulnerability of the EU-MS explains the non-significance of climate variables (*heat_dd* and *cool_dd*) with reference to the EP equation. This occurs as EP is a phenomenon that in EU-MS s is not determined by weather events, but rather by income-related factors.

The cooling use is correlated with middle-high-income households [49] and, therefore, the negative and significant *cool_dd* coefficient in the equation of the model concerning IP is an expected result. The inability to pay domestic utilities is a clear sign of economic inadequacy that identifies a direct relationship with both EP and IP. For this reason, a significant and positive correlation is revealed both in the EP, and in the IP equations.

4.2. Diagnostics

The results obtained with the model specified in the previous paragraph were stressed out with a series of diagnostic tools to assess their robustness (Table 4). The first check was performed through the Lagrange Multiplier Test for balanced panels to verify the presence of a significant individual (country-specific), which is the first methodological hypothesis underlying the methodological specification. The presence of these effects cannot be excluded. The results, in fact, lead us to reject the null hypothesis of absence of panel effects in the residuals of the model.

Table 4. Panel causality test and robustness checks.

Test for Panel Effects	**13.277 *****
Test for serial correlation	5.868
Test for cross sectional correlation	0.515

*** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05.

Under the assumption that this country-specific component is correlated with the exogenous variables, we discarded the hypothesis of the random nature of the country-specific effects (in which it is assumed that there is no correlation between the individual-specific component and the exogenous variables). Random nature requires strong assumptions on the individual effects that can hardly be engaged in the empirical macro applications [50].

The method is robust only if the model residuals are not affected by serial and cross -sectional correlation. For this reason, we carried out some other checks: the Breusch–Godfrey/Wooldridge and Pesaran tests for serial correlation (null hypothesis: no correlation in the residuals), and cross-sectional dependence (null hypothesis: no cross-sectional dependence) in the residuals of panel models [51]. The results show that the null is accepted in the PVAR specification.

5. Policy Implications

According to European Union estimates, EP involves over 50 million people, and as argued by the European Observatory for Energy Poverty (EPOV), people living in inadequately heated or cooled homes has implications on people's physical and mental health, and their well-being, with even an effect on economic development. Therefore, efforts issued by policy makers to reduce energy poverty (EP) are welcomed for their positive effect in terms of overall poverty reduction and quality-of-life improvement.

The findings suggest that a causal nexus between EP and IP exists, confirming the so-called feedback hypothesis. This means that policy makers must design a political intervention aimed at coordinating efforts targeted at improving citizens' living conditions and well-being, being able to eradicate poverty *latu sensu*. Policy makers must be aware that actions designed to tackle EP or IP will also have beneficial effects on the other. So, it is no longer necessary to think about two distinct areas of poverty, but they must come together within a single framework.

In the last ten years, the issue of EP has become a key point on the agenda of the EU. Nevertheless, a shared framework of EP is still lacking. Often, EP tends to be identified with income poverty (IP), as EP is usually associated with the occurrence of four basic conditions: (i) energy-inefficient housing; (ii) high energy prices; (iii) low income; and (iv) behaviour of individuals, where the last condition reflects behaviours that are not always rational but influenced by the context [38]. Anyway, EP is something that goes beyond individual poverty [52].

The current indeterminacy makes the policies to tackle EP overall ineffective. For this reason, it is important to support policy makers in promoting actions reducing EP, as well as to look for specific measures that follow EP evolution.

This result, apparently obvious, hides a deep meaning owing to the causal relationship existing in terms of the inverse relationship. That is, EP is an intrinsic aspect of overall poverty. Often this feature is not taken into account in the development of poverty indicators with as much reverence as income and unemployment thresholds. In fact, at risk-of-poverty persons are those with: (i) an equivalised disposable income under the risk-of-poverty threshold; and/or (ii) living in households with very low work intensity; and/or (iii) severely materially deprived of standard devices [53].

As a consequence, a family with an income just above the poverty threshold and a job would not be able to keep its house adequately warm, even if it cannot be considered at risk of poverty. Hence, EP emerges as an additional and independent form of deprivation that goes beyond pure income and employment indicators [14].

If EP is crucial in explaining overall poverty, the implementation of policies aimed at reducing EP could have a positive effect in terms of IP, even with regard to that component of the population that is not directly defined as poor. This assumption transversely affects the typical two main categories of policies tackling EP: short term protection policies aimed to ensure a minimum level of access to energy (such as income support and price cuts), and medium-long term promotion policies finalised to reach structural improvement of the condition of fragile individuals (such as greater energy awareness, redistributive effects of decarbonisation policies, energy efficiency of buildings and enforcement of social capital). Indeed, by virtue of the EP complexity, a deepening of its structural determinants cannot ignore the study of the processes underlying the families' choices concerning the energy efficiency, energy consumption, energetic behaviour and personal income [54].

Nevertheless, in the last decades, several projects and support schemes were developed to address the problem of EP directed mainly to enhance the energy efficiency of buildings and to the provision of households' income support through the recognition of tax credits aimed at partially covering incurred costs. These policies were mostly used by families who were not in conditions of EP, and were claimed only by a share (35%) of the eligible [10]. So, not surprisingly, the effect of these policies has not achieved the expected results. By their own nature, in fact, policies are fragmented and also affected by the bureaucratic delays that discourage their use. Additionally, these initiatives are often implemented on a local basis, without coordinated interventions.

6. Conclusions

This paper investigates the causal nexus between EP and IP in a panel of EU-Member States (MS) using a panel VAR model specification. To comprehensively address this research question, the study considers a wide number of control variables to describe the relationship between EP and IP. Moreover, to assess the robustness of the results, we also check for the presence of Granger causality.

The results of the model proposed indicate that an intervention that could be really effective is the encouraging of the shifting away from fossil fuels, replacing oil and coal with renewable energy sources. That is because these actions also have a beneficial effect on energy prices (peak shaving), which could increase [55]. As claimed in the last report on energy prices published by [56], prices have fallen in the last two years due to the increasing generation of energy from renewable sources, and to the improving interconnections of the internal electricity market. Especially in low-income countries, the reduction in energy costs for homeowners may alleviate poverty by ensuring access to electricity to people that historically never had access to energy. This is even more true and relevant at the current moment in which the prices of fossil energy sources are rising worldwide [57].

However, while an adequate level of knowledge about the benefits that can derive from incentivising renewable energies within the EU has been achieved, there are no specific EU directives aimed to incorporate the EP issue into the legislation of every MS. The fragmentation of the legislative framework about EP causes each country to autonomously determine polices able to better support housing conditions, in doing so disregarding the recommendations of the European Parliament on measures "that could be taken at the European, national and local levels to promote a more cohesive understanding of EU housing activities". Consistently with the study's findings, it appears that this is the main challenge that needs to be addressed to reduce EP.

The households that are unable to meet the costs for utilities and those claiming to have material deprivation within their homes are concentrated in well-defined areas of the European continent. They must be supported with specific measures that do not yet exist. Above all, by considering that the improvement of their living conditions will have the effect of reducing inequalities between different European countries, and will therefore provide economic leverage for the whole EU, the problem must be addressed as soon as possible without further delay. Some major threats may derive from the economic and social damage caused by pandemic, and the funds provided by the "Next Generation EU" plan could be an opportunity to bring up also this emergence. However, this issue does not seem to be among EU priorities.

Several important research directions arise. Indeed, to better define the nexus between EP and IP, a relevant contribution may come from a detailed geographic representation of the EP distribution able to individuate at various levels of granularity, the areas where the concentration of economic and energy hardship is greater. An investigation with a higher level of granularity can be utilised to develop tailor-made (sub)country-based actions focused on the factors resulting from econometric analysis, as those are most likely to reduce EP. Surveys allowing the estimates to be extended to micro-areas are, therefore, required.

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