Energy Policy 161 (2022) 112597

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Forecasting the COVID-19 effects on energy poverty across EU member states

Alfonso Carfora [a], Giuseppe Scandurra [b], Antonio Thomas [c,*]

[a] Italian Revenue Agency, Via C. Colombo Roma, Italy
[b] Department of Management and Quantitative Studies, University of Naples Parthenope, Napoli, Italy
[c] Department of Business and Economic Studies, University of Naples Parthenope, Napoli, Italy

A R T I C L E I N F O

Keywords:
Energy poverty
COVID-19 pandemic
EU member States
DFA analysis

A B S T R A C T

The COVID-19 pandemic is manifesting its devastating effects in multiple directions, even indirectly affecting the health of citizens, for instance, by increasing the level of energy poverty (EP). As part of the studies that are trying to frame the consequences of the pandemic, this paper aims to identify the effects on EP in the coming years in a bid to identify the countries of the European Union most affected and the time span necessary to return to a path to reduce EP. For this purpose, an analysis based on the supervised learning algorithms of dynamic factor models is carried out. The outcomes of this investigation show that the negative effects of the pandemic on the level of EP will be reabsorbed very slowly, not before 2025, and in any case with substantial differences between countries, further widening the gap between countries with low levels of EP and those with greater EP levels.

1. Introduction

Since its beginning, the COVID-19 pandemic has raised the issue of its impact on the global economy, the consequences on countries' national health and welfare systems, and the most suitable measures to mitigate it. The World Bank (2020) estimated that in 2020 between 88 and 115 million people would have been pushed into extreme poverty, with an increase to a range between 119 and 124 million in 2021. Among them, over 5 million people are from Europe and central Asia.

These issues have been attracting the attention of scholars of many disciplines, and a research stream dealing with the issue of the pandemic's burden on energy poverty (henceforth EP) has recently arisen because the pandemic is not only a health and economic crisis but also a social crisis, even an energy justice crisis, with rising energy troubles in multiple directions (Sovacool et al., 2020; Hoang et al., 2021). Many people are experiencing a reduction in essential energy services due to job loss or higher costs for energy; other people are becoming more vulnerable because of exposure to environmental pollution associated with energy production, and incentives to step up fossil energy consumption have even emerged (Brosemer et al., 2020; Haxhimusa and Liebensteiner, 2021; Quitzowa et al., 2021).

This situation is justifying and prompting a global wave of studies showing relevant dynamics for the purpose of determining EP as well as policy measures to protect people in vulnerable situation (Fell et al., 2020; Mastropietro et al., 2020). For instance, Bahmanyar et al. (2020) and Bienvenido-Huertas (2021) have pointed out how confinement actions exacerbate pre-existing EP issues by increasing residential demand due to higher occupancy and by reducing the income of many families economically affected by the crisis. Both these consequences enhance the difficulties of people living in uncomfortable homes, as a decline in many families' incomes makes it more difficult to pay energy bills (Jiang et al., 2021; Werth et al., 2021). In general, vulnerable households are expected to be the most affected class of people with respect to the negative effects of the pandemic in terms of EP (Abu-Rayash and Dincer, 2020; Sovacool et al., 2020). Consistently, several European countries have adopted binding measures prohibiting suppliers disconnecting customers in default. However, all these measures appear insufficient to limit the pandemic's effects on EP resulting from a deterioration in the living conditions of segments of the population (Pye and Dobbins, 2015; Nagaj and Korpysa, 2020). Conversely, the expected growth in energy-poor households actually limits the effectiveness of the policies promoted by the European Commission to reach the UN Sustainable Development Goals. Moreover, the fragmentation of legislation adopted in each European Union member state (EU-MS) is a consequence of this

* Corresponding author. Department of Business and Economic Studies, University of Naples Parthenope, Napoli, Italy.
E-mail address: antonio.thomas@uniparthenope.it (A. Thomas).

https://doi.org/10.1016/j.enpol.2021.112597
Received 20 April 2021; Received in revised form 31 August 2021; Accepted 10 September 2021
Available online 17 September 2021
0301-4215/

uncertainty about the individuation of EP, but it is also the reason explaining the absence of a harmonised system of European policies to tackle EP (Kerr et al., 2019). Not by chance, while all countries have included vulnerable consumers in their regulatory framework, only five countries (United Kingdom, France, Slovakia, Ireland, Cyprus) have legislated EP (Dobbins et al., 2019).

The lack of a shared norm in the EU-MS and the difficulty in individuating the drivers of EP able to mitigate the economic crisis following the pandemic amplify the consequences of the pandemic itself on EP and make it worthwhile to estimate the time span needed for reabsorbing this shock. However, although many studies have focused on the impacts of COVID-19 on energy demand and consumption globally, or at the level of individual countries, the effects of the pandemic on EP among EU-MS have not yet been clearly quantified.

With this in mind, this paper aims to assess the impact of COVID-19 on EP in 26 EU-MS.[1] Starting from the individuation of the main factors influencing EP in EU-MS, it reviews the effects generated by the pandemic on EP in the short and medium term. In addition, the paper identifies the time needed for EU-MS to return to the virtuous path they have followed in the recent past to tackle EP.

Following Bouzarovski (2014: 276), EP is here meant as "a situation in which a household lacks a socially and materially necessitated level of energy services in the home. In the context of the EU, causes and consequences of EP largely coincide with those of the more narrowly defined notion of 'fuel poverty', which has attracted a significant amount of public attention, scientific research, and state policy". According to the first official formulation, which still remains in place some 20 years later in many countries, a household is said to be fuel poor if it needs to spend more than 10% of its income on fuel to maintain an adequate level of warmth (Boardman, 1991).[2] Bouzarovski et al. (2012) also specify that fuel poverty is mainly used to describe low energy affordability, while EP is a wider term that includes problems related to energy accessibility. However, the mentioned definition suggests that EP is a multidimensional concept encompassing heterogeneous aspects, such as the difficulties in keeping one's home at a comfortable temperature, arrears in utility payments, the presence of leaks, damp and rot in the dwelling, which should be jointly taken into account for its correct specification (Romero et al., 2018; Halkos and Gkampoura, 2021).

To reach the proposed aims, the empirical research follows a two-stage analysis system based on the supervised learning algorithms of dynamic factor analysis (DFA). It is a technique usually employed to detect common patterns in a set of time series and relationships between these series and explanatory variables. In the first stage, an analytical econometric model capable of identifying the factors influencing EP has been estimated using a fixed-effects panel model. In the second stage, the dynamics of EP in EU-MS is taken into account, and an assessment is made of how long, and where, the effects of the pandemic will have a prolonged negative impact over the years. Predictions follow a one-year-ahead stepwise procedure (Kauppi and Saikkonen, 2008) and take into account the estimated coefficients in the panel. Fixed and variable effects were added to the estimates to predict the change in the outcome variable in each EU-MS.

The empirical analysis employed a large set of 26 variables collected from different Eurostat databases covering the years 2007–2018 for 26 EU-MS and summarised them according to a small number of dynamic factors. Next, these factors were used, together with gross domestic product (GDP) – as the exogenous variable – to develop a panel model to analyse the determinants of EP. Afterwards, by exploiting their autoregressive nature, these factors were forward projected through a one-step-ahead procedure and exploited, along with the predictions of exogenous variables provided by independent institutions, to make short- and medium-term forecasts on the expected values of EP levels.

The major contributions of this study are highlighted as follows:

1. In contrast to the predominant literature (eg, Recalde et al., 2019; Nagaj and Korpysa, 2020), in which the determinants of EP are based on the observation of a restricted number of variables (directly measured), in this paper, the factors affecting EP are based on the latent multidimensional syntheses given by the dynamic factors. This makes it possible to analyse several variables jointly without increasing interpretation difficulties and without using selection or shrinkage algorithms (e.g. LASSO) to limit the original data set to the main variables only.
2. Novel perspectives have been provided with respect to how to consider and analyse the energy patterns of each EU-MS. In every country, EP presents heterogeneous characteristics determined by many factors, including policies and changes in the pandemic landscape over time.
3. For each country, we provide precise expected values of EP in the short (2022) and medium term (2025).

To reach these aims, the paper primarily intends to quantify the effects of the pandemic on the energy discomfort of European households. Compared to the extensive literature on the COVID pandemic, the contribute provides clear indications of an important feature about the effect of the pandemic that has forced people to increase the amount of time spent indoors.

The remainder of this paper is organised as follows. Section 2 explains the method and its empirical application. Sections 3 and 4 show the results in terms of sample model estimation and forecasting. Section 5 proposes an in-depth investigation about the EU countries most affected by the pandemic. Section 6 concludes the paper.

2. Method and empirical application

2.1. Method

DFA is a statistical dimension-reduction technique for time-series data able to model simultaneously data sets in which the number of series exceeds the number of time-series' observations. It has been used in econometric (Harvey, 1989) and psychological fields (Molenaar, 1985; Molenaar et al., 1992) since the mid-1980s for testing models of relationships between variables. The mathematics underlying DFA are rather complex, the parameters are estimated by direct optimization, allowing larger data sets. DFA can also be applied to model short time series in terms. A full detail on these aspects can be found in Zuur et al. (2003) where the technique is illustrated on a marine environmental data set, demonstrating the large variety of application areas.

With this method, starting from a large number of variables, it is possible to get an outcome for a relatively small number of *m* common dynamic factors among the high-dimensional panel of *k* time series. The number of estimated dynamic factors is equal to the original number of time series from which they are extracted. They capture the full variability of the variables as a whole.

The dynamic factors have two main characteristics: *i)* they are

[1] Countries included are (ISO 2 code in parentheses): Belgium (BE), Bulgaria (BG), Czechia (CZ), Denmark (DK), Germany (DE), Estonia (EE), Ireland (IE), Greece (EL), Spain (ES), France (FR), Croatia (HR), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Hungary (HU), Netherlands (NL), Austria (AT), Poland (PL), Portugal (PT), Romania (RO), Slovenia (SI), Slovakia (SK), Finland (FI), Sweden (SE). Despite the recent exit from the EU, the United Kingdom (UK) was also considered. Due to the lack of a complete time series, Cyprus (CY) and Malta (MT) have not been included.

[2] The basic principles of Boardman's definition were challenged in 2012 by Hills, who focused on factors determining the quality and type of energy services received in the home. Hills' definition combines a threshold of poverty (expressed as 60% of the median) as a proportion of after-housing-costs income with a measure of high energy requirement in monetary terms relative to the wider population. However, this approach attracted a significant amount of controversy, as it is expected to lead to a meaningful reduction in the projected number of fuel-poor households.

uncorrelated, and the variability component grasped by each factor is not proportional; *ii)* a small number of factors explains most of the overall variability. This implies that each time series can be explained by a small set *m* of factors with $m << k$ and that DFA yields a fine-grained microscopic description of time-dependent processes, thus avoiding the risk of biased estimation due to collinearity. The idea underlying the DFA, in fact, is that a set of time series (*y*) is modelled as a linear combination of unobserved dynamic factors (*x*) and dynamic factor loadings (*Z*), plus some explanatory variables (*d*).

As an autoregressive process drives the dynamic factors, a DFA model has the following structure:

$$\boldsymbol{y}_t = \boldsymbol{Z}\boldsymbol{x}_t + \boldsymbol{d} + \boldsymbol{e}_t$$

where y_t is a $N \times 1$ vector of the values of the N time series at time t; x_t represents the values of the M common trends at time t, and e_t is a $N \times 1$ noise component, which is assumed to be normally distributed with a mean of 0 and a general covariance matrix ($\boldsymbol{\Sigma}$). The $N \times M$ matrix Z contains the factor loadings and determines the exact form of the linear combinations of the common trends. They are modelled as:

$$\boldsymbol{x}_t = \boldsymbol{x}_{t-1} + \boldsymbol{w}_t$$

where $\mathbf{w_t} \sim N(0,\mathbf{Q})$, $\mathbf{Q}$ is a diagonal error covariance matrix, and $\mathbf{w_t}$ is independent of e_t. Hence, the generic trend at time t is equal to the generic trend at time t – 1 plus a contribution of the noise component. The dynamic factors that resulted from the linear combinations – reducing the dimensionality of the original sets of variables – should be used as regressors in several model specifications and aim to explain temporal variations in the observed time series. The results, consequently, can be employed for forecasting purposes.

2.2. Empirical application

The empirical approach was based on the choice of time series data, consistent with literature (Recalde et al., 2019; Betto et al., 2020; Nagaj and Korpysa, 2020). Furthermore, the: *i*) relevance to the research questions, *ii*) measurability and *iii*) availability of reliable data is adequate to capture the various elements able to describe EP.

The outcome variable was drawn from the EU Statistics on Income and Living Conditions (EU-SILC). It collects timely and comparable cross-sectional and longitudinal multidimensional microdata. Among the large amount of data collected, Eurostat quantifies the share of population unable to keep their homes adequately warm (*enp*). This indicator is sometimes identified with *income poverty* because it is usually associated with the occurrence of four basic conditions: *i)* energy-inefficient housing, *ii)* high energy prices, *iii)* low income and *iv)* the behaviour of individuals.

Consistent with the adopted definition of EP, recently Bouzarovsky et al. (2020) have suggested that *enp* goes beyond income poverty since a household with an income just above the poverty threshold and a job might not be able to keep its house adequately warm, even if the household cannot be considered at risk of poverty. Hence, it is an additional and independent form of deprivation that goes beyond pure income and employment indicators. This indicator is commonly applied in research on EP (Marchand et al., 2019). Unfortunately, the multidimensional approach that would require the use of a synthesis method such as composite indicators (e.g. Halkos and Gkampoura, 2021) would only allow us to carry out a comparative analysis across countries by estimating the ranking for each country and the possible variation over time, not giving any empirical measure of the phenomenon that is the main aim of this paper. For this reason, we opted to use a proxy for a defined variable, which is widely used.

Starting from the pioneering approach of Healy and Clinch (2004) in the first fully comparative study of EP across the EU, the ability to keep a house adequately warm has often been used as a primary indicator capturing the various aspects of the EP (e.g., Karpinska and Smiech, 2020). It represents the outcome variable, both in studies that investigate EP in single countries (e.g., Aristondo and Onanindia, 2018) and in those focusing on the effects of EU energy policies about the EP (e.g., Primc and Slabe-Erker, 2020).

The explicative variables have been selected taking the indications coming from the EU Energy Poverty Observatory, the scientific literature (Betto et al., 2020; Fuerst et al., 2020; Nagay and Korpysa, 2020) and other relevant aspects (such as time span and data availability for the EU-MS) into account. For the 2007–2018 time span, 26 time series have been selected. Data descriptions are in Table 1, while the descriptive statistics are reported in Table 2. All data come from the Eurostat database.

The variables identified for the analysis were then grouped into four homogeneous thematic areas on the basis of their relevance. We assumed that these areas were the most relevant factors influencing EP: *i)* demographic and social conditions, *ii)* living conditions, *iii)* energy and *iv)* environment.

i) Demographic and social conditions summarise the aspects of economic deprivation and demographic pressure in EU-MS. We expected a direct relationship between the coefficient of this area

Table 1
Data definitions of explicative variables.

Eurostat thematic area	Dynamic factor	Time series	Description
Demographic and social conditions	psc	pop	Population on 1 January
		pov	Population (%) at risk of poverty
		educ	Population (%) with tertiary education (lev. 5–8)
		unemp	Uneployment rate (on population)
Energy	ene	ren_ sh	Share of energy from renewable sources
		noren_sh	Share of energy from no renewable sources
		ren_ele	Gross electricity production from Renewables
		noren_ele	Gross electricity production from no Renewables
		ei	Energy intensity of GDP in chain linked (2010)
		imp_sh	Share of imports of fuels on total
		el_imp	Imports of electricity and derived heat
		imp_dep	Energy dependence: net imports/available energy
		opf_imp	Imports of solid fossil fuels - Thousand tonnes
		elprice	Electricity prices for household consumers
		elprice_c	Electricity prices for non-household consumers
		gprices	Gas prices for household consumers
		en_cons	Final energy consumption
		inve_ren	Electricity production capacities for renewables
Environment	env	ghg	Greenhouse gases
		ghg_pc	Per capita greenhouse gases
		waste	Generation of waste per GDP unit
		bovine	Bovine population
		env_rev	Environmental revenues on total tax revenues
Living conditions	liv	arrears	Population (%) with arrears on utility bills
		hous_cos	Share of housing costs in disposable income
		hous_dep	Population (%) with severe housing deprivation

Table 2
Descriptive statistics.

Time series	Median	Std. Deviation	Range	Minimum	Maximum
pop	9,742,867	23,657,074	81,037,909	534,237	81,572,146
pov	23.28	7.32	30.79	14.28	45.07
educ	24.43	6.76	22.86	13.25	36.11
unemp	0.45	0.07	0.34	0.38	0.72
ren_ sh	0.23	0.24	0.81	0.07	0.88
noren_sh	0.77	0.24	0.81	0.12	0.93
ren_ele	2,142	7,781	27,991	127	28,117
noren_ele	10,156	34,429	122,973	521	123,494
ei	156.39	90.10	391.04	75.17	466.21
imp_sh	0.13	0.05	0.19	0.07	0.26
el_imp	12,002	10,585	44,776	1,352	46,127
imp_dep	51.18	23.29	96.85	−0.20	96.65
opf_imp	17,206	52,586	180,462	1,701	182,163
elprice	0.15	0.05	0.20	0.09	0.29
elprice_c	0.12	0.03	0.15	0.09	0.24
gprices	0.13	0.05	0.19	0.07	0.26
en_cons	20.39	54.46	210.75	2.90	213.65
inve_ren	5,826	19,179	79,855	452	80,307
ghg	69,308	231,630	940,719	11,874	952,593
ghg_pc	1,501	4,552	19,091	196	19,287
waste	76.17	141.78	664.17	30.17	694.33
bovine	9.46	3.88	18.31	5.80	24.10
env_rev	7.42	1.66	5.75	5.01	10.76
arrears	7.23	8.54	28.93	2.25	31.18
hous_cos	20.64	5.11	21.76	14.48	36.23
hous_dep	4.43	6.03	22.32	0.74	23.06

and EP. Increases in the individual indicators that make up this area would lead to a deterioration in demographic and social conditions, increasing the share of households in energy poverty.

ii) Living conditions condense the housing deprivation conditions of households, including the share of population in arrears on utility bills, housing costs and disposable income, and the population with severe housing deprivation. The worsening of housing conditions is reflected, as is well known, in an increase in the same indicators. For this reason, a positive coefficient was also expected here.

iii) Energy refers both to the composition of generation sources and to the prices of energy sources.

iv) Environment summarises the greenhouse and methane emissions (GHG and bovine), waste and the effect of environmental taxes. Similar considerations apply to the last two areas. Here, too, we expected positive coefficients.

Then, we estimated through the DFA one ($m = 1$) latent country i-trend for each area: the one that accounts for most of the variability in each group.

For a generic i-country, each y-time series for $j = 1, \ldots, 4$ thematic areas can be expressed by the correspondent dynamic factor so that:

$$\begin{bmatrix} y_{it}^1 = & Zx_{it-1}^1 + & d + e_{it}^1 \\ \vdots & \vdots & \vdots \\ y_{it}^4 = & Zx_{it-1}^4 + & d + e_{it}^4 \end{bmatrix}$$

The model dynamic factors (x_1, x_2, x_3, x_4) were estimated through a maximum-likelihood method based on a Monte Carlo initial conditions search. The algorithm (EM) steps up the likelihood and the convergence test is based on the rate of change of the log-likelihood in each step (Holmes et al., 2012). The Z parameters have a specific form, and the multivariate covariance matrix of the residual components e is set at i.i.d (diagonal) with variance of 1.

Moreover, as dynamic factors summarise most of the overall variability of the sets of the variables from which they have been extracted, they were used, lagged for one year in a panel analysis of the determinants of EP of the type:

$$enp_{it} = \alpha_i + \sum_{j=1}^{4} \beta_j x_{it-1}^j + \gamma r_{it} + u_{it} \tag{1}$$

where, for $t = 2007, \ldots, 2018$, α_i are the country time invariant fixed effects, x_{it-1}^j represents the factor extracted while r is an exogenous regressor accounting for the business cycle, and u_{it} is the disturbance with zero mean.

3. Results

The dynamic factors are autoregressive by construction, but it is not guaranteed that they are also stationary; for this reason, we checked for the presence of unit roots in the series (Harvey, 1989). To this end, we tested the integration order of the dynamic factors using both the first generation of Levin et al.'s (2002) panel data unit root test, and the second-generation CIPS unit root test (Pesaran, 2007). The latter is stricter since it allows for cross-sectional dependence. Table 3 reports the results for the unit root tests. They suggest that the null for the presence of unit root in panel data cannot be accepted.

Using the within estimator with homoscedastic consistence covariance matrix, we obtained the coefficient estimates of the model specification (eq. (1)). The results are reported in Table 4. The coefficients were all significant and in line with the expected results. The estimates were robust in terms of the slope of coefficients: the Wald-F test led us to reject the null hypothesis that the slope coefficients of the model were jointly equal to zero. Moreover, we tested for the presence of significant individual effects through the Breusch-Pagan Lagrange Multiplier Test and for the presence of cross-sectional correlation among countries through the average absolute correlation test. From the first check, the results led us to reject the null hypothesis of the absence of significant individual (country) effects; from the second check, the results led us to accept the null hypothesis of the absence of cross-sectional dependence between countries.

Finally, in order to evaluate the predictive accuracy of the model, we carried out some in-sample forecasts using a one-year-ahead stepwise procedure (Kauppi and Saikkonen, 2008). The procedure started by estimating a model using data from the beginning of the sample up to a particular t-year. Next, the estimated coefficients were used to make a one-step-ahead prediction which requires that the $t+1$ observation be added to the sample, and a new model was estimated to form new forecasts and so on. In this way, the procedure ensured that the forecasts were obtained using only the information available in the past; that is, data available after the forecast were not used to obtain it.

In order to forecast the country EP in $t = 2016$, we firstly estimated the model using the observations from the beginning ($t = 2007$) until $t = 2015$. Then, we employed the estimated coefficients to obtain the prediction for the next year. In order to get the $t = 2017$ predicted value, the coefficients obtained through the application of the model on the data until $t = 2016$ (2007–2015 observed and $t = 2016$ predicted) were used and so on. This sequential procedure allowed us to make a comparison between the predicted and observed values, leading to a fairer and more realistic test of the predictive abilities of the different models than the in-sample results. For the EU-MS, we estimated E(Y) from $t = 2016$ to $t = 2018$, using the one-year-ahead stepwise procedure, obtaining three of

Table 3
Panel unit root tests statistics.

Time series	Pesaran	CIPS
psc	−7.926***	−1.926***
ene	−4.763***	−1.669**
env	−9.208***	−2.867***
liv	−10.377***	−3.171**
gdp	−15.484***	−3.050**

Sign:***99%; **:95%; *:90%.

Table 4
Fixed model estimates.

variable	coefficient	std Error	p-value
psc(t-1)	0.668	0.123	0.000
ene(t-1)	0.152	0.083	0.068
env(t-1)	0.257	0.117	0.029
liv(t-1)	0.770	0.121	0.000
gdp	−0.407e-04	7.591e-05	0.000
Model tests			
Wald F			0.000
Lagrange Multiplier (Breusch-Pagan)			0.000
Average absolute correlation			0.464
RMSE			2.759
MAE			1.917

the sample's yearly forecasts for each county, for a total of 78 (3 x 26) forecasts.

The last two rows of Table 4 report the mean absolute error (MAE) and the root mean square error (RMSE). They measure the test-set forecast accuracy based on the difference between actual value and forecast value [Y_i – $E(Y_i)$] and are considered two of the best-known predictive accuracy indices for non-seasonal time series (Hyndman and Koheler, 2006).

$$\mathrm{MAE}=\frac{\sum_{i=1}^{78}|Y_i-E(Y_i)|^2}{78};\quad \mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{78}(Y_i-E(Y_i))^2}{78}}$$

Both indices have low values, confirming that the proposed model is able to capture the heterogeneity of EP and confirm the accuracy of the proposed model.

The most explicative dynamic factor of the demographic and social conditions thematic area, *psc,* which summarises four time series ($m=1$; $k=4$), is significant and positive. This is in line with a well-recognised result in the literature concerning the evidence that in the EU-MS the probability of EP decreases if energy policies are integrated towards social policy (Primc and Slabe Erker, 2020). Therefore, the *psc* dynamic factor develops a synthetic indicator of worsening the social conditions as linked with the unemployment rate and greater demographic pressure directly related to EP. It expresses a measure, across different domains, of inequality in access to services and of the inefficiencies of the social needs for the households, as demonstrated by Bollino and Botti (2017) for the EU. Even the most explicative dynamic factor of the energy thematic area, *ene,* which summarises 14 time series ($m=1$; $k=14$) is significant and positive. It is an indicator derived from a panel of variables related to generation, prices, imports and energy efficiency; for this reason, we interpreted this factor as an indicator of domestic energy demand.

Lately, the changing climate patterns have greatly influenced energy demand, especially in South East Europe where the increase in external temperatures has increased household vulnerability, also resulting in a growing energy demand (European Environment Agency, 2017). For this reason, we interpret the direct and significant relationship of the indicator with EP as a signal of households who respond to their vulnerability with a growing demand for indoor space cooling and air conditioning. Since this leads to an increase in stress on the power grids and conflicts with carbon reduction goals, many scholars have converged on the assumption that COVID-19 is a challenge to envisage a low-carbon future (Abu-Rayash and Dincer, 2020; Howarth et al., 2020; Kanda and Kivimaa, 2020).

Env summarises a set of five variables ($m=1$; $k=5$) indicating the degree of environmental degradation due to the impact of agriculture, industrial and urban activities and the government tax measures aimed to reduce it. The indicator is related to EP, thus confirming the results highlighted in some recent studies (e.g. Chakravarty and Tavoni, 2013), which indicate that EP eradication requires a reduction in the climate change direct impacts. This goal can be reached through an increase in clean energy generation as well as a reduction in greenhouse gas emissions (GHG) (Tol, 2018).

The last dynamic factor *liv* summarises three variables ($m=1$; $k=3$) identifying household restraints in energy consumption due to the inability to afford energy services. This indicator, in line with the outcomes of previous studies (Romero et al., 2018; Betto et al., 2020) emphasises the role of the energy inefficiency of buildings, which is an important determinant of EP for EU households.

As suggested by Llorca et al. (2018), income is one of the main drivers of EP. In addition, one of the tangible aspects of the economic crisis caused by the pandemic was the severe contraction of GDP as a result of the necessary mitigation measures introduced by the various countries, which led to closures or restrictions being imposed on economic activities. For this reason, the GDP at market prices, *gdp* (measured in current prices), was included as an exogenous regressor in the model specification together with the synthetic indicators expressed by the dynamic factors. In this way, it was possible to capture the reaction of EP to cyclical fluctuations characterised by peaks and troughs. As expected, EP followed a counter-cyclical pattern: during business expansion phases the tendency is towards a general reduction and the opposite during recession phases.

4. Forecasting energy poverty in European countries

Together with the investigation of the factors affecting EP, the paper aspires to carry on a forecast analysis on the level of EP, focusing with greater consideration on the impact of COVID-19 on EP's evolutionary path. The expected value of EP for a generic year $t+h$, $E(enp_{t+h})$, with $h=1, \ldots, n$ is conditioned on the set of information, $E(\mathbf{X})$, that is available at time t

$$E(enp_{t+h})=\beta' E(\mathbf{X})+E(u_t)=\beta' E(\mathbf{X}) \tag{2}$$

because $E(u_t)=0$ by construction.

The matrix **X** of the explanatory variables in eq. (2) includes the dynamic factors that, by construction, follow an autoregressive path and the level of GDP on which EC and the IMF provide reliable estimates. In this section, three different scenarios related to the expected short- and medium-term EP path are presented. Using the GDP forecasts provided by both international organisations and the forward deploys of the internal estimates of the dynamic autoregressive factor, we provide:

- a short-term forecast (by 2022), based on estimates provided by Eurostat;
- medium-term forecast (until 2025), based on two different scenarios proposed by the International Monetary Fund (IMF): one optimistic (upside) and one pessimistic (downside).

4.1. The European Commission short-term scenario

The short-term outlook for the EU-MS provided by the European Commission (2021) is forecast to still pick up moderately. In fact, GDP is forecast to grow by 3.7% in 2021 and 3.9% in 2022. However, the speed of recovery will vary significantly across the EU. Some countries have suffered more during the pandemic than others, whereas some are more dependent on sectors such as tourism, which are likely to remain weak for some time. This heterogeneity in the recovery will also have effects on the trend of EP which, after an increase in 2020 (of different degrees of intensity among countries), will decrease at different speeds.

The expected 2022 levels of EP are obtained by estimating the expected values (from $t=2019$ to $t=2021$) of the dynamic factors with a stepwise procedure:

$$E(x_{2019})=c+\phi x_{2018}$$

$$E(x_{2021})=c+\phi E(x_{2020})$$

The stepwise predicted 2019–2022 dynamic factors and the EC 2019–2022 GDP forecasts ($\widehat{gdp}$) are then used to forward deploy through the panel model coefficients estimated with equation (1):

$$E(enp_{i2019}) = \alpha_i + \beta_1 psc_{i2018} + \beta_2 ene_{i2018} + \beta_3 env_{i2018} + \beta_4 liv_{i2018} + \gamma gdp_{i2019}$$

$$E(enp_{i2020}) = \alpha_i + \beta_1 E(psc_{i2019}) + \beta_2 E(ene_{i2019}) + \beta_3 E(env_{i2019}) + \beta_4 E(liv_{i2019}) + \gamma \widehat{gdp}_{i2020} \quad (3)$$

$$E(enp_{i2022}) = \alpha_i + \beta_1 E(psc_{i2021}) + \beta_2 E(ene_{i2021}) + \beta_3 E(env_{i2021}) + \beta_4 E(liv_{i2021}) + \gamma \widehat{gdp}_{i2021}$$

The 2022 short-term forecasts, constrained to the minimum positive estimated value, are reported in Table 5, while Fig. 1 plots a synthetic comparison between the last observed values of the EP indicator (t = 2019) and the short-term forecasts (t = 2022).

In Table 5, for each short-term forecast, the lower and upper bounds of the estimated value are provided. They have been obtained using in specification (3) the lower and upper bounds of the 99% confidence intervals ($\alpha = 0.01$) of the estimated fixed model coefficients, respectively (reported in Table 4).

The joint observation of Fig. 1 and Table 5 shows that, in all countries, the impact of the pandemic will lead to a worsening of the conditions of European households; it will increase the share of energy-poor households, although at different speeds. In t = 2022, only a few countries—those below the bisector in Fig. 1 (Ireland, Denmark, Holland, Sweden and Slovakia)—will be at lower levels of EP than they were before the pandemic. On the other hand, countries such as Bulgaria, Greece, Latvia and Italy will suffer more from energy poverty; in these countries, at t = 2022, an increase of about 10% is expected for households in energy poverty compared to pre-pandemic levels.

4.2. The IMF middle-term scenarios

A wider medium-term forecasting horizon has been provided by the IMF (2021) in its periodical *World Economic Outlook*, in which the economic aspects of the 2023–2025 middle-term horizon are explored according to two alternative scenarios: a very optimistic one, the upside, and a pessimistic one, the downside. Both scenarios are focused on the key uncertainties underlying the outlook: incidence of COVID infections and efficacy of vaccine roll-out.

Differently from the European Commission (EC, 2021), the IMF does not provide detailed estimates for each country, but it only indicates growth rates for homogeneous groups of countries (advanced economies, emerging market and developing economies). In the upside scenario, the level of global output increases for the advanced economies by roughly 1% in t = 2023, and it will continue to increase, with negative elasticity, until t = 2025, when it will rise by an increase of roughly 0.5%. In the downside scenario, the level of global output decreases, for t = 2023, and the economy's growth rate becomes negative. An economic stagnation is expected, for which growth rates ranging from −0.5% in t = 2023 to −0.2% in t =2025[3] are expected.

The stepwise predicted 2023–2025 dynamic factors and the IMF 2023–2025 GDP forecasts obtained assuming GDP fluctuations in each country, in line with the rates expected by the IMF following the two scenarios ($\widehat{gdp^U}$; $\widehat{gdp^D}$), were then used to forward deploy through the panel model coefficients estimated (see eq. (1)). In the middle-term upside scenario, in line with the empirical application deployed for the near-term one:

$$E(enp_{i2025}) = \alpha_i + \beta_1 E(psc_{i2024}) + \beta_2 E(ene_{i2024}) + \beta_3 E(env_{i2024}) + \beta_4 E(liv_{i2024}) + \gamma \widehat{gdp}^{U}_{i,2025} \quad (4)$$

Similarly, in the middle-term downside scenario:

$$E(enp_{i2025}) = \alpha_i + \beta_1 E(psc_{i2024}) + \beta_2 E(ene_{i2024}) + \beta_3 E(env_{i2024}) + \beta_4 E(liv_{i2024}) + \gamma \widehat{gdp}^{D}_{i,2025} \quad (5)$$

The t = 2025 middle-term upside and downside scenarios are reported in Table 6 together with the 99% confidence interval. They have been obtained using in the (4) and (5) specifications respectively the lower and upper bounds of the confidence intervals of the estimated fixed model coefficients (reported in Table 4). Fig. 2 reports a synthetic comparison of the last observed values of the EP indicator (t = 2019) and

[3] More details are available in the online full report of the *World Economic Outlook* that can be consulted at: https://www.imf.org/en/Publications/WEO/Issues/2021/01/26/2021-world-economic-outlook-update.

Table 5
2022 short term forecasts (in parentheses, the lower and upper bound of 99% confidence interval for EU-MS).

Country	2019		2020		2021		2022	
Austria	1.8		2.71		3.52		2.36	
	(0.00;	*7.35)*	*(0.00;*	*5.55)*	*(0.90;*	*6.13)*	*(0.00;*	*5.01)*
Belgium	3.9		4.71		6.51		6.77	
	(0.00	*9.43)*	*(1.94*	*7.47)*	*(3.89*	*9.13)*	*(3.92*	*9.61)*
Bulgaria	30.1		43.48		44.42		45.35	
	(29.79	*30.41)*	*(43.32*	*43.63)*	*(44.39*	*44.45)*	*(45.19*	*45.51)*
Croatia	6.6		3.13		5.2		6.91	
	(6.55	*6.65)*	*(3.10*	*3.15)*	*(5.01*	*5.39)*	*(6.31*	*7.51)*
Czech R.epublic	2.8		3.28		4.44		5.12	
	(0.80	*4.80)*	*(2.29*	*4.28)*	*(3.39*	*5.48)*	*(3.83*	*6.41)*
Denmark	2.8		3.62		3.65		2.2	
	(0.00	*10.55)*	*(0.00*	*7.75)*	*(0.00*	*7.53)*	*(0.00*	*6.13)*
Estonia	2.5		2.65		3.14		3.26	
	(0.00	*5.84)*	*(0.97*	*4.32)*	*(1.54*	*4.73)*	*(1.64*	*4.88)*
Finland	1.8		1.66		2.15		1.61	
	(0.00	*6.12)*	*(0.00*	*4.32)*	*(0.00*	*4.72)*	*(0.00*	*4.27)*
France	6.2		5.27		6.78		6.45	
	(1.47	*10.93)*	*(2.90*	*7.64)*	*(4.58*	*8.99)*	*(4.02*	*8.88)*
Germany	2.5		2.43		3.42		3.51	
	(0.00	*7.18)*	*(0.09*	*4.76)*	*(1.16*	*5.68)*	*(1.03*	*6.00)*
Greece	17.9		26.12		26.21		25.31	
	(14.66	*21.14)*	*(24.50*	*27.74)*	*(24.80*	*27.61)*	*(23.90*	*26.72)*
Hungary	5.4		9.2		9.87		9.92	
	(3.93	*6.87)*	*(8.47*	*9.93)*	*(9.10*	*10.64)*	*(9.01*	*10.83)*
Ireland	4.9		0.07		0.64		0.07	
	(0.11	*9.69)*	*(0.00*	*4.79)*	*(0.00*	*5.28)*	*(0.00*	*4.76)*
Italy	11.1		14.63		16.86		16.31	
	(7.72	*14.48)*	*(12.94*	*16.32)*	*(15.15*	*18.58)*	*(14.52*	*18.11)*
Latvia	8		16.14		16.66		16.83	
	(5.34	*10.66)*	*(14.81*	*17.47)*	*(15.40*	*17.93)*	*(15.51*	*18.15)*
Lithuania	26.7		29.18		29.28		28.83	
	(23.99	*29.41)*	*(27.82*	*30.53)*	*(27.95*	*30.61)*	*(27.54*	*30.13)*
Luxembourg	2.4		2.06		2.89		0.65	
	(0.00	*11.22)*	*(0.00*	*8.82)*	*(0.00*	*9.29)*	*(0.00*	*7.24)*
Netherlands	3		0.45		1.89		1.2	
	(0.00	*6.33)*	*(0.00*	*3.33)*	*(0.00*	*4.75)*	*(0.00*	*4.15)*
Poland	4.2		6.37		7.29		7.69	
	(3.38	*5.02)*	*(5.96*	*6.77)*	*(6.79*	*7.78)*	*(7.07*	*8.31)*
Portugal	18.9		22.56		24.03		24.69	
	(17.26	*20.54)*	*(21.74*	*23.38)*	*(23.18*	*24.87)*	*(23.58*	*25.81)*
Romania	9.3		10.86		12.06		13.02	
	(9.07	9.53)	(10.74	10.97)	(12.00	12.12)	(12.73	13.31)
Slovakia	7.8		5.95		6.2		5.71	
	(5.09	*10.51)*	*(4.59*	*7.30)*	*(4.94*	*7.45)*	*(4.41*	*7.01)*
Slovenia	2.3		2.77		3.51		3.26	
	(0.00	*4.63)*	*(1.61*	*3.94)*	*(2.38*	*4.65)*	*(1.95*	*4.57)*
Spain	7.5		7.78		9.02		8.51	
	(3.75	*11.25)*	*(5.90*	*9.65)*	*(7.37*	*10.68)*	*(6.76*	*10.27)*
Sweden	1.9		0.8		0.8		1.01	
	(0.00	*4.64)*	*(0.00*	*2.74)*	*(0.00*	*3.88)*	*(0.00*	*4.35)*
United Kingdom	5.4		8		9.07		8.16	
	(0.00	*11.06)*	*(5.16*	*10.83)*	*(6.56*	*11.58)*	*(5.67*	*10.65)*

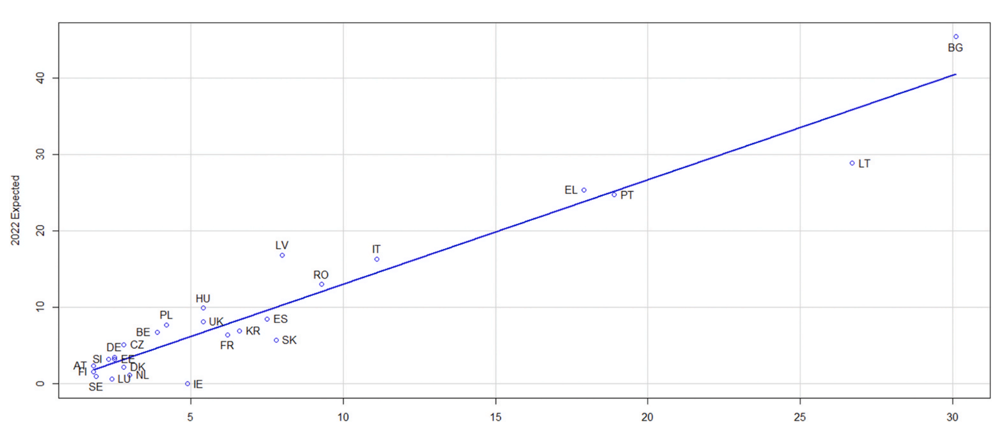

Fig. 1. 2019 vs expected 2022 EP levels under the near-term EU Commission scenario.

Table 6
Middle term expected EP (in parentheses, the lower and upper bound of 99% confidence interval for EU-MS).

	IMF upside scenario						IMF downside scenario					
Country	2023		2024		2025		2023		2024		2025	
Austria	2.07		2.03		2.00		2.07		2.21		2.30	
	(0.00	*4.84)*	*(0.00*	*4.84)*	*(0.00*	*4.85)*	*(0.00*	*4.84)*	*(0.00*	*5.00)*	*(0.00*	*5.10)*
Belgium	5.99		5.67		5.44		5.99		5.85		5.72	
	(3.10	*8.88)*	*(2.80*	*8.55)*	*(2.58*	*8.30)*	*(3.10*	*8.88)*	*3.01*	*8.69)*	*(2.92*	*8.53)*
Bulgaria	46.28		46.3		46.36		46.28		46.33		46.41	
	(45.92	*46.63)*	*(45.92*	*46.68)*	*(45.95*	*46.77)*	*(45.92*	*46.63)*	*(45.96*	*46.70)*	*(46.02*	*46.81)*
Croatia	6.96		7.11		7.23		6.96		7.17		7.33	
	(6.27	*7.65)*	*(6.36*	*7.85)*	*(6.44*	*8.02)*	*(6.27*	*7.65)*	*(6.43*	*7.90)*	*(6.56*	*8.10)*
Czech Republic	4.81		4.63		4.49		4.81		4.72		4.63	
	(3.38	*6.24)*	*(3.20*	*6.06)*	*(3.05*	*5.92)*	*(3.38*	*6.24)*	*(3.30*	*6.14)*	*(3.23*	*6.04)*
Denmark	1.76		1.42		1.17		1.76		1.67		1.57	
	(0.00	*5.86)*	*(0.00*	*5.50)*	*(0.00*	*5.23)*	*(0.00*	*5.86)*	*(0.00*	*5.70)*	*(0.00*	*5.55)*
Estonia	3.18		2.63		2.29		3.18		2.71		2.42	
	(1.57	*4.79)*	*(1.10*	*4.17)*	*(0.81*	*3.78)*	*(1.57*	*4.79)*	*(1.19*	*4.23)*	*(0.96*	*3.88)*
Finland	1.19		0.63		0.56		1.19		0.82		0.86	
	(0.00	*3.94)*	*(0.00*	*3.35)*	*(0.00*	*3.32)*	*(0.00*	*3.94)*	*(0.00*	*3.50)*	*(0.00*	*3.56)*
France	6.43		6.08		5.83		6.43		6.25		6.09	
	(3.84	*9.03)*	*(3.48*	*8.68)*	*(3.23*	*8.43)*	*(3.84*	*9.03)*	*(3.68*	*8.82)*	*(3.54*	*8.65)*
Germany	3.18		3.09		3.04		3.18		3.27		3.33	
	(0.59	*5.76)*	*(0.45*	*5.73)*	*(0.37*	*5.72)*	*(0.59*	*5.76)*	*(0.67*	*5.87)*	*(0.71*	*5.95)*
Greece	24.49		24.37		24.29		24.49		24.46		24.43	
	(23.07	*25.91)*	*(22.95*	*25.79)*	*(22.87*	*25.70)*	*(23.07*	*25.91)*	*(23.06*	*25.86)*	*(23.04*	*25.82)*
Hungary	9.78		9.63		9.53		9.78		9.7		9.63	
	(8.71	*10.84)*	*(8.57*	*10.69)*	*(8.47*	*10.58)*	*(8.71*	*10.84)*	*(8.65*	*10.75)*	*(8.60*	*10.67)*
Ireland	0.07		0.07		0.07		0.07		0.07		0.07	
	(0.00	*4.30)*	*(0.00*	*3.88)*	*(0.00*	*3.52)*	*(0.00*	*4.30)*	*(0.00*	*4.13)*	*(0.00*	*3.93)*
Italy	16.83		15.85		16.66		16.83		15.98		16.87	
	(14.83	*18.84)*	*(13.96*	*17.75)*	*(14.60*	*18.72)*	*(14.83*	*18.84)*	*(14.11*	*17.86)*	*(14.85*	*18.89)*
Latvia	16.86		16.22		16.53		16.86		16.29		16.63	
	(15.53	*18.19)*	*(15.02*	*17.43)*	*(15.27*	*17.78)*	*(15.53*	*18.19)*	*(15.09*	*17.48)*	*(15.39*	*17.87)*
Lithuania	28.31		28.51		28.63		28.31		28.58		28.74	
	(27.07	*29.56)*	*(27.22*	*29.80)*	*(27.31*	*29.95)*	*(27.07*	*29.56)*	*(27.30*	*29.86)*	*(27.45*	*30.04)*
Luxembourg	0.65		0.65		0.65		0.65		0.65		0.65	
	(0.00	*6.50)*	*(0.00*	*5.99)*	*(0.00*	*5.63)*	*(0.00*	*6.50)*	*(0.00*	*6.35)*	*(0.00*	*6.20)*
Netherlands	0.45		0.49		0.54		0.45		0.69		0.87	
	(0.00	*3.47)*	*(0.00*	*3.56)*	*(0.00*	*3.65)*	*(0.00*	*3.47)*	*(0.00*	*3.73)*	*(0.00*	*3.92)*
Poland	7.96		8.28		8.55		7.96		8.35		8.66	
	(7.23	*8.69)*	*(7.48*	*9.08)*	*(7.70*	*9.40)*	*(7.23*	*8.69)*	*(7.56*	*9.14)*	*(7.82*	*9.49)*
Portugal	24.74		25.01		25.34		24.74		25.1		25.48	
	(23.52	*25.96)*	*(23.72*	*26.31)*	*(23.97*	*26.71)*	*(23.52*	*25.96)*	*(23.82*	*26.38)*	*(24.14*	*26.82)*
Romania	13.21		13.44		13.63		13.21		13.49		13.7	
	(12.81	*13.61)*	*(12.97*	*13.91)*	*(13.11*	*14.15)*	*(12.81*	*13.61)*	*(13.03*	*13.94)*	*(13.19*	*14.21)*
Slovakia	5.26		5.06		4.89		5.26		5.14		5.01	
	(3.93	*6.60)*	*(3.72*	*6.39)*	*(3.56*	*6.22)*	*(3.93*	*6.60)*	*(3.82*	*6.46)*	*(3.71*	*6.32)*
Slovenia	3.14		2.98		2.83		3.14		3.08		3.00	
	(1.66	*4.62)*	*(1.50*	*4.46)*	*(1.36*	*4.30)*	*(1.66*	*4.62)*	*(1.62*	*4.54)*	*(1.56*	*4.44)*
Spain	8.04		7.94		7.88		8.04		8.06		8.08	
	(6.19	*9.88)*	*(6.08*	*9.81)*	*(6.00*	*9.76)*	*(6.19*	*9.88)*	*(6.22*	*9.91)*	*(6.23*	*9.92)*
Sweden	0.49		0.28		0.13		0.49		0.51		0.49	
	(0.00	*3.93)*	*(0.00*	*3.75)*	*(0.00*	*3.63)*	*(0.00*	*3.93)*	*(0.00*	*3.94)*	*(0.00*	*3.92)*
United Kingdom	7.29		7.45		7.27		7.29		7.61		7.52	
	(4.86	*9.71)*	*(4.97*	*9.94)*	*(4.79*	*9.75)*	*(4.86*	*9.71)*	*(5.15*	*10.06)*	*(5.09*	*9.95)*

the middle-term forecasts ($t = 2025$). Over a broader horizon, if the most optimistic IMF scenario occurs, additional countries should improve their EP status: Austria, Belgium, Finland and Spain are expected to have lower EP rates than $t = 2019$ and will join the small group of those who will have improved their status as early as in $t = 2022$. Extending the perspective to the middle term, the countries which in the short-term analysis are distinguished by a worsening of their EP indicators are expected to improve their status after $t = 2022$; but criticism and difficulties are still awaited regarding their capacity to recover the gap that has arisen compared to the pre-pandemic period. This is the case for Bulgaria, Greece, Latvia and Italy, which, similarly to what has already been observed with the short-term forecasts, will continue to suffer from the effects of the pandemic in the coming years, slowing the return of the rate of EP households over time. The effects in these countries will last longer.

The $t = 2025$ middle-term downside scenario identifies a similar state to that of the $t = 2022$ medium-term scenario and thus a persistence of the condition achieved after the $t = 2020$ pandemic shock and the initial response due to the natural immediate upturn. If such a scenario occurs, the countries will go through a period of at least 5 years of substantial stagnation in their condition of income poverty, with strong consequences in terms of social conditions and mainly in terms of transition towards improvements in their energy efficiency.

5. A deeper investigation about the eight EU-MS most affected by COVID-19

The European Centre for Disease Prevention and Control is monitoring the COVID-19 pandemic and assessing the specific degree of risk for each EU-MS. The Centre displays on weekly basis the absolute

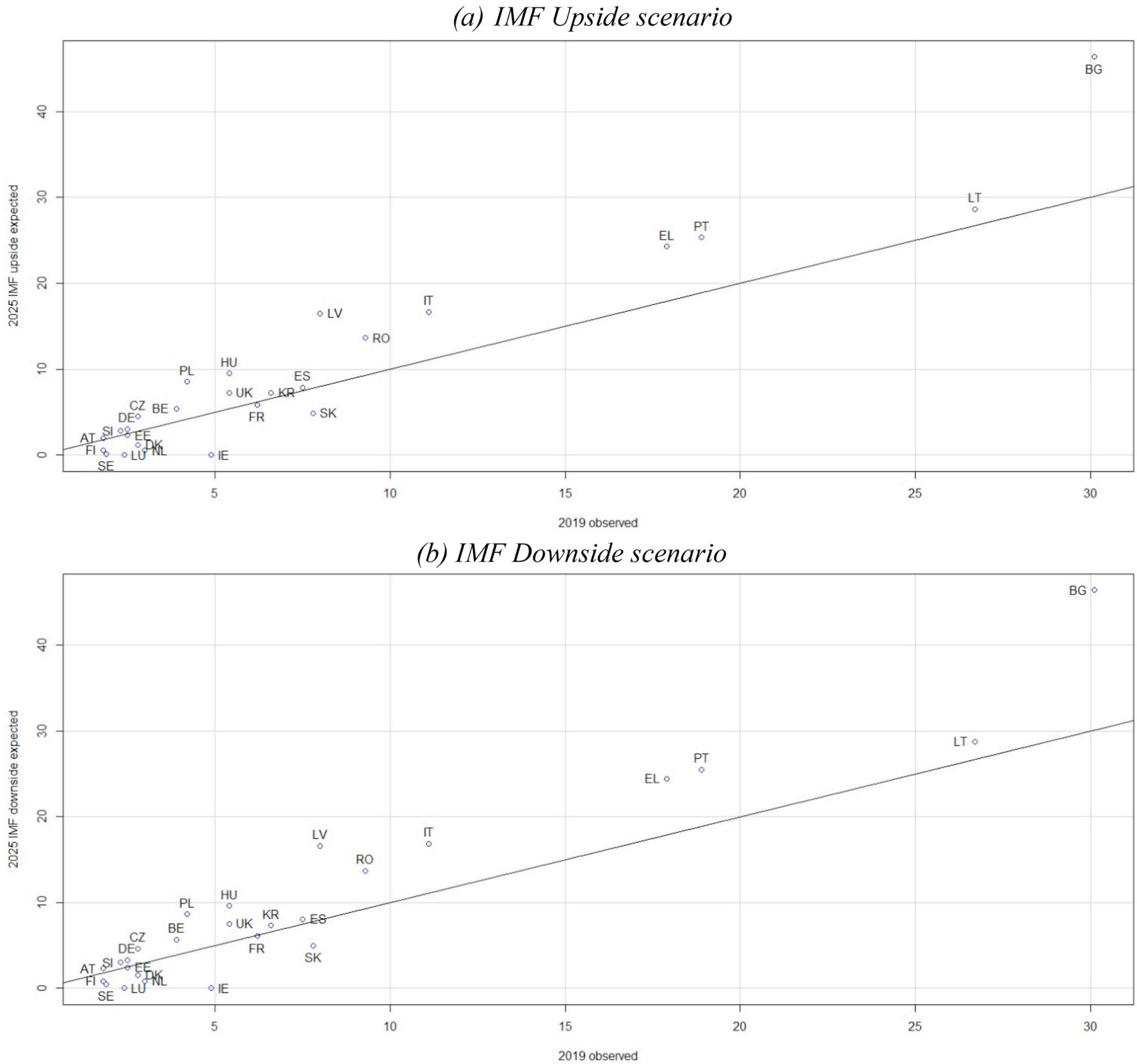

Fig. 2. 2019 vs expected 2025 EP levels under the middle-term IMF upside (a) and downside (b) scenarios.

numbers of contagious cases and the incidence in the population.[4] Transmission is widespread in the EU, and still in the 10th week of 2021, the numbers of people infected are very high. Due to COVID-19, around one third of countries are suffering from increases in hospital or intensive care admissions and from a reduction of employment in firms. These consequences of the pandemic will remain for at least all of 2021, fuelled by variants of the pandemic that make the benefits of mass vaccinations waning with time, as recently demonstrated by Lopez Bernal et al. (2021) and Pouwels et al. (2021). With this in mind, this section carries out a supplementary analysis on the eight countries most affected by the pandemic (in terms of cases per 100,000 inhabitants) in order to identify those that will be able to experience an earlier recovery and those in which the consequences will persist longer in terms of EP.[5] In Fig. 3, we report the detailed expected trends of countries' EP until $t = 2025$.

For Czechia and Estonia, two similar trends are expected. Both countries started with a similar pre-pandemic index of EP (about 2.5%),

[4] The latest updates are available at: https://www.ecdc.europa.eu/en/cases-2019-ncov-eueea.

[5] The following analysis is based on evidence at week 10 in 2021. Evidently, heterogeneity in COVID diffusion across countries and changes in estimates of GDP growth rates may alter the forecasts themselves. In line with the ranking of the Centre in March 2021, Czechia, Estonia, France, Hungary, Latvia, Slovakia, Slovenia and Sweden were selected. The authors are also pleased to provide a similar supplement for any of the other countries in the sample upon request.

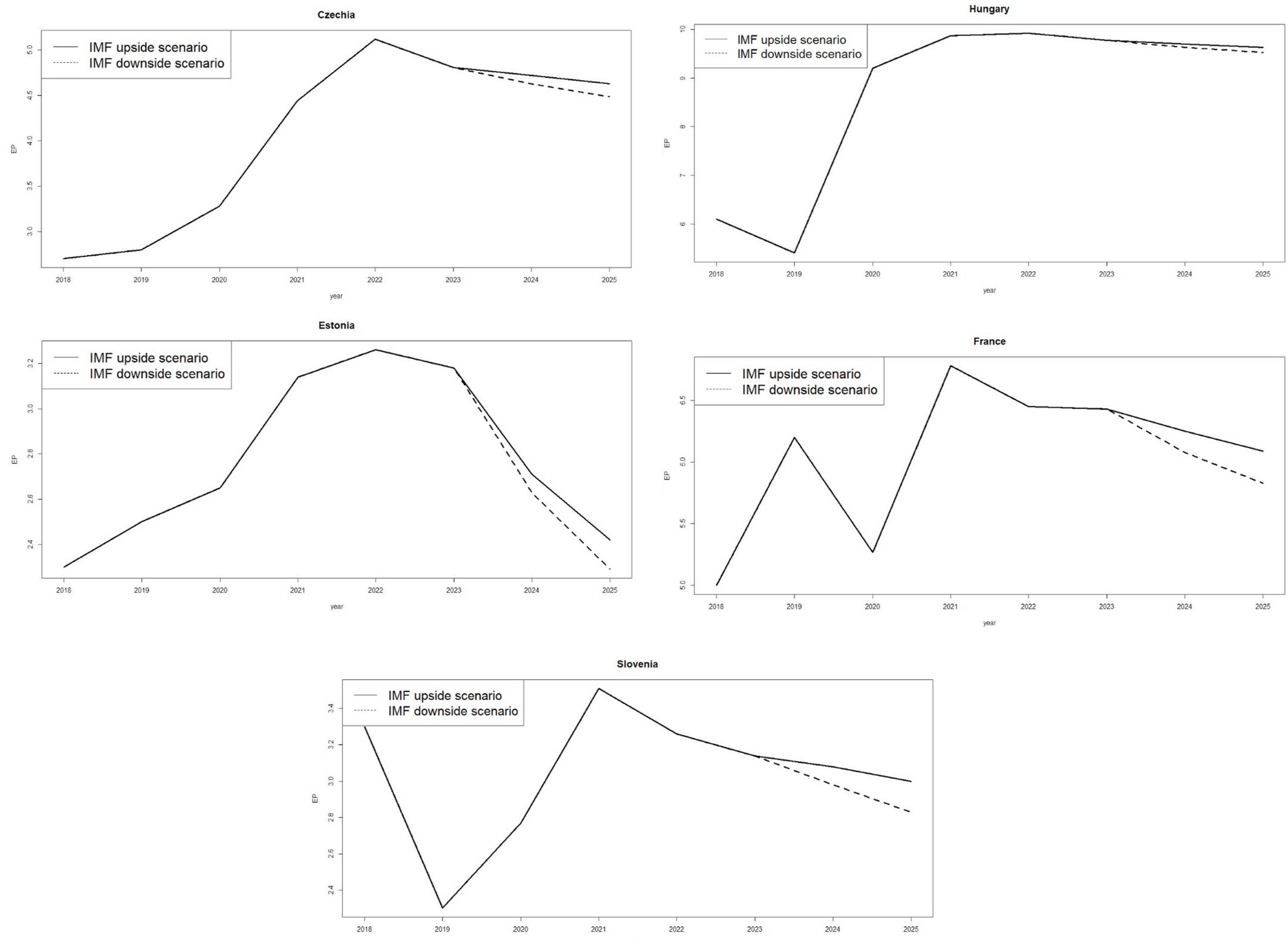

Fig. 3. Focus on EP levels in some EU-MS.

and both the countries will be affected by a rapid increase in EP until $t = 2022$. After $t = 2022$, under both IMF economic growth scenarios, Czechia (1,395 cases per 100,000 inhabitants in March 2021) and Estonia (1,038 cases per 100,000 inhabitants in March 2021) will experience an improvement in the general situation. It will be faster in the latter than the former, but it will not stop with the countries returning to pre-pandemic EP levels. Hungary (452 cases per 100,000 inhabitants in March 2021) and Latvia (497 cases per 100,000 inhabitants in March 2021) seem to be the more critical countries since they will be affected by a sharp increase in EP (+4% and +8% respectively) which, once it has occurred, will settle at very high levels. We expect a structural break in the series that does not seem to be fully recovered until the end of the 2025, even if the more optimistic IMF scenario occurs.

France (432 cases per 100,000 inhabitants in March 2021), Slovakia (562 cases per 100,000 inhabitants in March 2021) and Slovenia (517 cases per 100,000 inhabitants in March 2021) will be at the same levels of EP in 2025, compared to pre-pandemic levels, whatever economic scenario occurs, even if they will be characterised by years of strong fluctuations. This is a signal that the structural framework of these countries is such that it right now provides an adequate level of resilience.

Lastly, there is the very hopeful case of Sweden. Sweden (489 cases per 100,000 inhabitants in March 2021) is, among the most affected countries, the one expected to respond best. It is expected that by 2025 its status will improve, and this will also occur in a shorter period of time given that due to the fact that for most of 2020 it did not enforce any sort of economic lockdown, the peak of the EP crisis will be reached 1 or 2 years later than in the other countries. Under the most optimistic scenario of the IMF, Sweden could reduce its EP levels to zero by 2025, confirming that among European countries, it is the one that is structurally better organised in terms of social and energy conditions to deal with the pandemic and to efficiently tackle the causes that have contributed to it.

6. Conclusions and policy implications

6.1. Discussion

The COVID-19 pandemic represents the most dramatic economic and social crisis since World War II. Even if according to the most optimistic expectations in terms of immunisation the achievement of so-called herd immunity will occur within 2021, social and economic consequences will persist for several years. For this reason, the analyses and research interests of an increasing number of scholars and insiders are focused on economic trends, inequality, damages and unemployment induced by the pandemic.

With this in mind, this paper aimed to contribute to the debate on the consequences of the economic crisis caused by the pandemic, focusing on the effect on EP among EU–MS and forecasting its dynamics in the

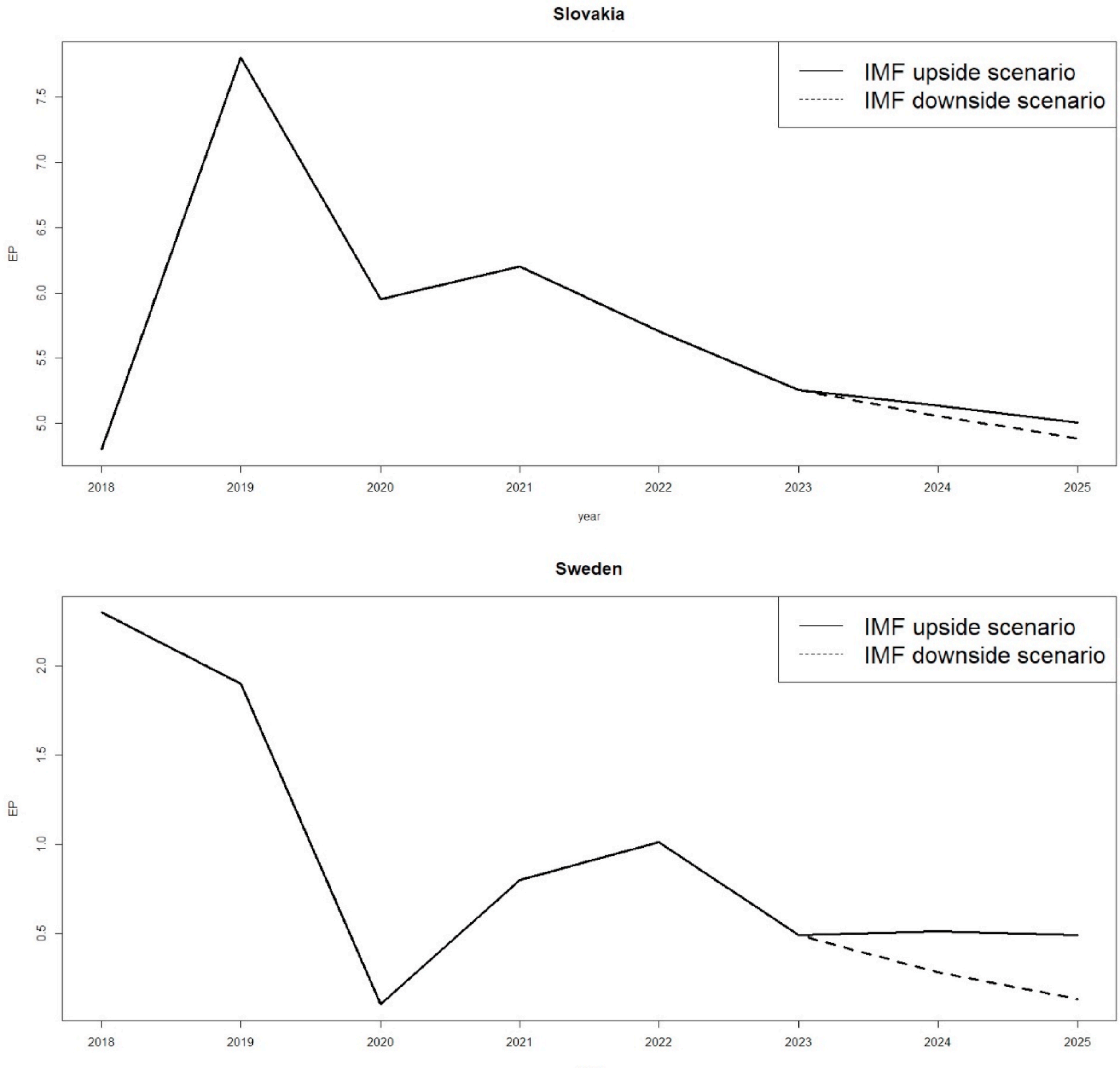

Fig. 3. (*continued*).

near future (until 2025). It also investigated when a return to the virtuous path that EU-MS have followed in the recent past to tackle EP could be undertaken.

To reach these aims, a statistical learning algorithm based on dynamic factors analysis was applied. Employing a comprehensive data set of 26 variables, we extrapolated four areas affecting EP: *i)* demographic and social conditions, *ii)* living conditions, *iii)* energy and *iv)* environment. To these, we have also considered GDP as a proxy for economic growth. The estimated coefficients for the four areas and GDP were all significant and in line with the expected sign, confirming that EP in EU-MS is affected by the proposed multidimensional latent factors and by economic growth.

The analysis conducted confirms that the increase in the incidence of energy-poor households due to worsening economic, social, environmental and energy conditions observed in the current framework will be absorbed slowly and heterogeneously among countries. Lockdown measures have brought the EU economies into recession phases leading to job losses in many sectors. According to the short-term forecasts, by 2022, based on estimates provided by Eurostat, Bulgaria, Greece, Latvia and Italy will suffer the worst results in terms of EP. On the other hand, the pandemic created new job opportunities in other sectors, such as public service, pharmaceuticals and media, enabling better prospects for several countries. This is the case for Ireland, Slovakia, the Netherland and Sweden, for which an improvement in EP conditions is expected within the short term.

Since the strong conditions of uncertainty related to a unique event in modern history may influence the results and assumptions of this investigation, for the medium-term analysis, two different scenarios proposed by the IMF (downside and upside) were considered. In both scenarios, many countries could reverse the upward trend in EP incidence, but only a few countries will be able to reduce EP to pre-pandemic levels. Even in these situations, the countries with the worst prospects are Bulgaria, Greece, Latvia and Italy. Conversely, the countries with the better prospects should be Ireland, Slovakia, Netherland and Sweden.

Our results also confirmed the most recent outcomes of research dealing with this issue. The impact of the global COVID-19 crisis and related policy responses vary across countries. Those with a weaker industrial structure or more dependent on sectors such as transportation and logistics and tourism have been impacted and are expected to suffer the worst effects, with a clear impact on the level of internal EP. In a nutshell, the effect of the pandemic has tended to deepen the gap between leaders and laggard countries in terms of EP, exacerbating already existing imbalances and hindering the international climate targets finalised to eliminate fossil energy consumption (Haxhimusa and Liebensteiner, 2021; Quitzowa et al., 2021).

The critical scenarios of countries that even before the pandemic had the most serious troubles with respect to EP are a striking feature of the results of this study. This consideration could also affect another aspect, not explicitly considered in this study, relating to the generation of renewable energy. A contraction in the development of renewables appears to be highly realistic (Bahmanyar et al., 2020; Hosseini, 2020).

6.2. Implications

As a consequence of the above assumptions, authorities at international, European and national levels should acknowledge that specific interventions are needed for each country to avoid further increases in inequalities with increasing EP. The main efforts of policymakers in tackling EP should be addressed towards the improvement of the welfare system and net employment. Moreover, as long as the energy supply is not sufficiently extensive to ensure high accessibility to people, the issue of EP will persist. Consistent with this aim, policymakers should devote more effort to implementing measures to improve the living and housing conditions of vulnerable households (Fell., 2020; Vernengo and Nabar-Bhaduri, 2020).

Thus, new measures are necessary, as it is unrealistic to return to pre-pandemic levels of EP in the medium term (by 2025). Only a few countries, those in which the phenomenon was already structurally weak, will be able to achieve this goal, while about half of the countries analysed will be in a worse condition than they were in the pre-pandemic era.

For these purposes, a central role will certainly be played by the so-called ‘Recovery Plan’ in light of the recent European Community recommendations (2020) on the need for part of these funds to be used to help households to reduce energy bills and to live in healthier living conditions. The injection of economic resources into the various economic systems expected by the recovery funds should be able to promote investments that succeed in accelerating growth, thereby reducing the social gaps between countries and promoting the transition to greener generation sources.

Energy and climate policies at the international level are also required given the necessity both to minimise the effects of pandemic on EP and to avoid a reduction in the share of renewable energies (Hosseini, 2020; Hoang et al., 2021). Policies should try to convert over the next few years the threats of pandemic into opportunities for renewables within a long-term trajectory, for instance, by stabilising changes connected to the digitalisation of work and other daily activities, and in doing so reducing mobility needs and fossil-energy consumption (Abu-Rayash and Dincer, 2020; Kanda and Kivimaa, 2020).

The range of objectives proposed to reduce energy consumption should consider that a large percentage of EU households have inadequate insulation, a state also caused by climate change. As previous studies (e.g. Damigos et al., 2021) have demonstrated that low-income households tend to focus on short-term over long-term outcomes and thus are more likely to make myopic decisions (the so-called discounting gap), significant energy saving programmes for residential buildings would help to mitigate EP. A reduction in energy costs could also be obtained through the supply side, stimulating providers to be more effective in their production methods or improving the level of market liberalisation. To tackle EP also implies adequate protection for customers in conditions of economic weakness. For this purpose, it would be appropriate to channel all the heterogeneous current electricity and gas bonuses into a unique instrument linked to the subjective risk of EP of each household. The latter is a very ambitious objective, given that the measurement criteria and the definition of EP still varies between EU countries, but is one which could guarantee many advantages and perhaps even an overall saving of financial resources to be invested in this direction.

Anyway, as underlined by Sovacool et al. (2021), without careful guidance and consideration, the new age wrought by COVID-19 risks collapsing in on itself with bloated stimulus packages that counter sustainability goals, misaligned incentives that exacerbate climate change, the entrenchment of unsustainable practices, and acute and troubling consequences for vulnerable groups.

To minimise this risk, the research agenda should include additional analyses to enforce the forecasted scenarios, when: *i*) more comprehensive forecasts on countries’ outlooks will be available for the medium and long term, *ii*) the progress of the vaccination campaign will have had a large impact, *iii*) funds from the Recovery Plan will have been actually transferred to the EU-MS and *iv*) new measurement indicators able to collect the multidimensional aspects of EP under more perspectives (e.g. energy costs and income, self-assessment, proxy indicators, direct measurement of specific variables) will have been proposed. At that time, it will be possible to provide reports with a longer horizon and more detailed scenarios. These are aims for further research.

CRediT authorship contribution statement

Alfonso Carfora: Methodology, Software, Data curation. **Giuseppe Scandurra:** Conceptualization, Formal analysis, Investigation, Writing – original draft, Validation. **Antonio Thomas:** Writing – original draft, Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2021.112597.

References

Abu-Rayash, A., Dincer, I., 2020. Analysis of the electricity demand trends amidst the COVID-19 coronavirus pandemic. Energy Res. Soc. Sci. 68, 101682.
Aristondo, O., Onaindia, E., 2018. Counting energy poverty in Spain between 2004 and 2015. Energy Pol. 113, 420–429.
Bahmanyar, A., Estebsari, A., Ernst, D., 2020. The impact of different COVID-19 containment measures on electricity consumption in Europe. Energy Res. Soc. Sci. 68.
Betto, F., Garengo, P., Lorenzoni, A., 2020. A new measure of Italian hidden energy poverty. Energy Pol. 138, 111237.
Bienvenido-Huertas, D., 2021. Do unemployment benefits and economic aids to pay electricity bills remove the energy poverty risk of Spanish family units during lockdown? A study of COVID-19-induced lockdown. Energy Pol. 150, 112117.
Boardman, B., 1991. Fuel Poverty: from Cold Homes to Affordable Warmth. Belhaven Press, London.
Bollino, C.A., Botti, F., 2017. Energy poverty in Europe: a multidimensional approach. PSL Q. Rev. 70 283, 473–507.
Bouzarovski, S., 2014. Energy poverty in the European Union: landscapes of vulnerability. WIREs Energy Environ. 3, 276–289. https://doi.org/10.1002/wene.89.
Bouzarovski, S., Petrova, S., Sarlamanov, R., 2012. Energy poverty policies in the EU: a critical perspective. Energy Pol. 49, 76–82.
Bouzarovski, S., Thomson, H., Cornelis, M., Varo, A., Guyet, R., 2020. Towards an Inclusive Energy Transition in the European Union: Confronting Energy Poverty amidst a Global Crisis. EU Energy Poverty Observatory, Luxembourg.
Brosemer, K., Schelly, C., Gagnon, V., Arola, K.L., Pearce, J.M., Bessette, D., Schmitt Olabisi, L., 2020. The energy crises revealed by COVID: intersections of Indigeneity, inequity, and health. Energy Res. Soc. Sci. 68, 101661.
Chakravarty, S., Tavoni, M., 2013. Energy poverty alleviation and climate change mitigation: is there a trade off? Energy Econ. 40, 67–73.

Damigos, D., Kaliampakou, C., Balaskas, A., Papada, L., 2021. Does energy poverty affect energy efficiency investment decisions? First evidence from a stated choice experiment. Energies 14, 1698. https://doi.org/10.3390/EN14061698.
Dobbins, A., Nerini, F.F., Deane, P., Pye, S., 2019. Strengthening the EU's response to energy poverty. Nat. Energy 4. https://doi.org/10.1038/S41560-018-0316-8.
European Commission, 2020. Recommendation of 14.10.2020 on energy poverty. https://ec.europa.eu/energy/sites/ener/files/recommendation_on_energy_poverty_c2020_9600.pdf.
European Commission, 2021. European Economic Forecast. Institutional Paper, p. 144.
European Environment Agency, 2016. Climate Change, Impacts and Vulnerability in Europe: an Indicator-Based Report.
Fell, M.J., Pagel, L., Chen, C-f., Goldberg, M.H., Herberz, M., Gesche, M., Huebner, G.M., Sareen, S., Hahnel, U.J.J., 2020. Validity of energy social research during and after COVID-19: challenges, considerations, and responses. Energy Res. Soc. Sci. 68, 101646.
Fuerst, F., Kavarnou, D., Singh, R., Adan, H., 2020. Determinants of energy consumption and exposure to energy price risk: a UK study. Immobilienökonomie 6, 65–80.
Halkos, G.E., Gkampoura, E.-C., 2021. Evaluating the effect of economic crisis on energy poverty in Europe. Renew. Sustain. Energy Rev. 144, 110981 https://doi.org/10.1016/j.rser.2021.110981.
Harvey, A.C., 1989. Forecasting, Structural Time Series Models and the Kalman Filter. Cambridge University Press.
Haxhimusa, A., Liebensteiner, M., 2021. Effects of electricity demand reductions under a carbon pricing regime on emissions: lessons from COVID-19. Energy Pol. 156, 112392.
Healy, J.D., Clinch, J.P., 2004. Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. Energy Pol. 32, 207–220.
Hills, J., 2012. Getting the Measure of Fuel Poverty: Final Report of the Fuel Poverty Review. Centre for Analysis of Social Exclusion, London School of Economics and Political Science, London.
Hoang, A.T., Nižetić, S., Olcer, A.I., Ong, H.C., Chen, W.-H., Chong, C.T., Thomas, S., Bandhj, S.A., Nguyen, X.P., 2021. Impacts of COVID-19 pandemic on the global energy system and the shift progress to renewable energy: opportunities, challenges, and policy implications. Energy Pol. 154, 112322.
Holmes, E.E., Ward, E.J., Wills, K., 2012. MARSS: multivariate autoregressive state-space models for analyzing time-series data. R J. 4, 11–19.
Hosseini, S.E., 2020. An outlook on the global development of renewable and sustainable energy at the time of COVID-19. Energy Res. Soc. Sci. 68, 101633.
Howarth, C., Bryant, P., Corner, A., Fankhauser, S., Gouldson, A., Whitmarsh, L., et al., 2020. Building a social mandate for climate action: lessons from COVID-19. Environ. Resour. Econ. 76, 1107–1115.
Hyndman, R.J., Koehler, A.B.z, 2006. Another look at measures of forecast accuracy. Int. J. Forecast. 22 (4), 679–688.
IMF (International Monetary Fund), 2021. World economic outlook, January. www.imf.org/en/Publications/WEO.
Kanda, W., Kivimaa, P., 2020. What opportunities could the COVID-19 outbreak offer for sustainability transitions research on electricity and mobility? Energy Res. Soc. Sci. 68, 101666.
Karpinska, L., Smiech, S., 2020. Conceptualising housing costs: the hidden face of energy poverty in Poland. Energy Pol. 147, 111819.
Kauppi, H., Saikkonen, P., 2008. Predicting U.S. recession with dynamic binary response models. Rev. Econ. Stat. 90, 777–791.
Kerr, N., Gillard, R., Middlemiss, L., 2019. Politics, problematisation, and policy: a comparative analysis of energy poverty in England, Ireland and France. Energy Build. 194, 191–200. https://doi.org/10.1016/j.enbuild.2019.04.002.
Levin, A., Lin, C., Chu, C., 2002. Unit root test in panel data: asymptotic and finite sample properties. J. Econom. 108, 1–24.
Llorca, M., Rodriguez-Alvarez, A., Jamasb, T., 2018. Objective vs. Subjective fuel poverty and self-assessed health. Energy Econ. 87, 104736.
Lopez Bernal, J., Andrews, N., Gower, C., et al., 2021. Effectiveness of covid-19 vaccines against the B.1.617.2 (Delta) variant. N. Engl. J. Med. 385 (7), 585–594. https://doi.org/10.1056/NEJMoa2108891.
Marchand, R., Genovese, A., Koh, S.C.L., Brennan, 2019. Examining the relationship between energy poverty and measures of deprivation. Energy Pol. 130, 206–217.
Mastropietro, P., Rodilla, P., Batlle, C., 2020. Emergency measures to protect energy consumers during the Covid-19 pandemic: a global review and critical analysis. Energy Res. Soc. Sci. 68, 101678.
Molenaar, P.C.M., 1985. A dynamic factor model for the analysis of multivariate time series. Psychometrika 50, 181–202.
Molenaar, P.C.M., de Gooijer, J.G., Schmitz, B., 1992. Dynamic factor analysis of nonstationary multivariate time series. Psychometrika 57, 333–349.
Nagaj, R., Korpysa, J., 2020. Impact of COVID-19 on the level of energy poverty in Poland. Energies 13, 4977.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econom. 22 (2), 265–312.
Pouwels, K.B., Pritchard, E., Matthews, P.C., et al., 2021. Impact of Delta on Viral Burden and Vaccine Effectiveness against New SARS-CoV-2 Infections in the UK. Preprint at Univ, Oxford. https://www.ndm.ox.ac.uk/files/coronavirus/covid-19-infection-survey/finalfinalcombinedve20210816.pdf.
Primc, K., Slabe-Erker, R., 2020. Social policy or energy policy? Time to reconsider energy poverty policies. Energy Sustain. Dev. 55, 32–36.
Pye, S., Dobbins, A., 2015. Energy Poverty and Vulnerable Consumers in the Energy Sector across the EU: Analysis of Policies and Measures. European Commission.
Quitzowa, R., Bersallia, G., Eickea, L., Jahna, J., Lilliestama, J., Liraa, F., Mariana, A., Süssera, D., Thapar, S., Wekoa, S., Williamsa, S., Xuea, B., 2021. The COVID-19 crisis deepens the gulf between leaders and laggards in the global energy transition. Energy Res. Soc. Sci. 74, 101981.
Recalde, M., Peralta, A., Oliveras, L., 2019. Structural energy poverty vulnerability and excess winter mortality in the European Union: exploring the association between structural determinants and health. Energy Pol. 133, 110869.
Romero, J.C., Linares, P., Lopez, X., 2018. The policy implications of energy poverty indicators. Energy Pol. 115, 98–108.
Sovacool, B.K., Del Rio, F.D., Griffiths, S., 2020. Contextualizing the Covid-19 pandemic for a carbon-constrained world: insights for sustainability transitions, energy justice, and research methodology. Energy Res. Soc. Sci. 68 https://doi.org/10.1016/j.erss.2020.101701.
Tol, R.S.J., 2018. The economic impacts of climate change. Rev. Environ. Econ. Pol. 12 (1), 4–25.
Vernengo, M., Nabar-Bhaduri, S., 2020. The economic consequences of COVID-19: the great shutdown and the rethinking of economic policy. Int. J. Polit. Econ. 49 (4), 265–277.
Werth, A., Gravino, P., Prevedello, G., 2021. Impact analysis of COVID-19 responses on energy grid dynamics in Europe. Appl. Energy 281.
World Bank, 2020. Global Economic Prospects 2020. World Bank Publications, Washington DC, ISBN 978-1-4648-1580-5.
Zuur, A.F., Fryer, R.J., Jolliffe, I.T., Dekker, R., Beukema, J.J., 2003. Estimating common trends in multivariate time series using dynamic factor analysis. Environmetrics 15, 665–685.