Impulse response of auction price by practicing auction scheme for solar PV generation to generation quantity, investment and Brent crude oil price

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Abstract: *Energy is crucial for economic progress worldwide, regardless of a country's development status. However, the negative impacts of traditional energy sources have prompted global policymakers to reconsider fossil fuel consumption patterns. In addition to these harmful effects, regional conflicts such as the Russia-Ukraine war and tensions involving Israel, Palestine, and Iran are contributing to instability in the global energy market, which in turn affects general market stability. Consequently, global leaders are focusing on country-specific energy policies that prioritize the transition to renewable energy sources in future energy strategies. To ensure the widespread and cost-effective use of solar photovoltaic energy, many countries, including those in the European Union and beyond, are increasingly utilizing renewable energy auction techniques. Thus, the primary focus of this study is to evaluate the impact of a competitive auction technique on the expansion of solar PV generation and the potential reduction (or stabilization) of Brent crude oil prices (i.e., West Texas intermediate oil price). This is particularly relevant given the shifting investment trends in the renewable energy sector, with a specific emphasis on seven open and dynamic economies within the EU. To conduct this analysis, the authors employed a panel vector autoregression (VAR) model, utilizing annual data spanning from 2000 to 2021. The result indicates that the competitive auction value for solar PV accelerates the generation of solar PV in the selected EU countries and the countries are likely to decrease their reliance on fossil fuel-based sources for electricity generation. Because, the auction price is becoming competitive to the Brent crude oil price. Further, the investment in the solar PV sector is not sufficient yet.*

Keywords: *Auction value, funds, panel VAR model, photovoltaic, West Texas intermediate oil price.*

JEL Classification: *C32, C62, Q42, Q48.*

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Introduction

Policies play a crucial role in fostering sustained and lasting development across various sectors, and the solar photovoltaic (solar PV) as a source of renewable energy sector is no exception to this fundamental principle. In the face of global efforts to address climate change, there is a projected 50% surge in energy demand by 2050, with the energy sector responsible for two-thirds of global emissions (IEA, 2018; IRENA, 2020). In 2019, global subsidies for renewable energy amounted to USD 170 billion. It is noteworthy that subsidies for fossil fuels during the same period were nearly twice that amount (REN21, 2019). Nevertheless, numerous renewable projects continue to rely on governmental subsidies for their implementation.

Decision-makers establish country-specific objectives based on energy policies to actualize a nation's energy vision. This approach contributes to market stability, boosts investor confidence, and facilitates the realization of energy support goals. In light of the adverse effects associated with conventional energy sources, there is a growing emphasis on shifting towards renewable energy sources (RES) in future energy strategies. According to Andrews-Speed (2016), the concept of a low-carbon energy transition stems from the understanding that energy and its consumption patterns are deeply ingrained in societies. Government intervention becomes imperative in the adoption of expensive energy transition technologies to ensure long-term public benefits. As a viable alternative energy source on a global scale, renewable energy (RE) as low-carbon energy is gaining prominence in response to challenges posed by climate change, the depletion of fossil fuels (FF), concerns about energy security, technological advancements, and the increasingly volatile prices of petroleum-based fuels (Do et al., 2020; Ferrer et al., 2018).

In facilitating the shift towards a low-carbon future, governmental authorities must find a harmonious equilibrium between internal and external factors and room to maneuvers. The former involves decisive actions taken by the government, while the latter entails employing strategic settings to guide the transition (Smith & Stirling, 2007). Corroborating the initial assertion, Andrews-Speed and Zhang (2015) affirm that advancing RE demands the establishment of limits, substantial financial backing from the state, and the implementation of robust administrative measures. These measures are essential to effectively circumvent the need for elusive strategic instruments.

In the early 21st century, renewable sources of energy (especially solar PV) assumed a more prominent position. Notably, from 2004 to 2017, there witnessed a rapid surge in investments in clean energy, with the funding escalating from USD 62 billion to USD 280 billion (Pham, 2019). While Brent crude oil remains a prevalent fossil fuel for energy generation, growing interest and investments in renewable energy sources as alternatives to fossil fuels have motivated researchers to explore potential relationships among various variables (Wu & Chen, 2019). The most recent Monthly electricity statistics report from the International Energy Agency (IEA), covering data up to October 2023, indicates a sustained upward trajectory in the utilization of renewable sources. There was a notable 7.0% year-on-year growth, primarily propelled by increased generation from solar (registering a substantial +15.8% year-on-years).

The Renewable energy directive (European Union, 2018) mandates that 32% of the energy consumed within the European Union must come from renewable sources by 2030. This directive, aligned with the European Green Deal, highlights the need for stronger climate action and environmental goals, focusing on energy's role in achieving net-zero emissions. To support these goals, the European Green Deal Investment Plan, launched in January 2020, aims to mobilize at least EUR 1,000 billion over the coming decade (European Commission, 2020). In the spread of renewable energy four barriers can be defined based on Sisodia et al. (2016): still higher costs compared to traditional energy sources, market share, governments' policy, and until the development of energy storage the matching demand for the energy produced.

To promote the expansion of solar PV, various governments implement policy supports and set targets with a focus on reducing emissions, ensuring energy supply security, and making energy sources more accessible (REN21, 2009; REN21, 2007). Despite the existence of diverse support schemes, governments frequently modify their choices due to factors such as changing political and institutional environments, the tightening of local or global targets, technological advancements, or challenges in providing support during financial crises (Boomsma et al., 2012). The political and economic necessities of the energy sector contribute significantly to the governance of this domain, with policy paradigms playing a crucial role (Helm, 2007; Kuzemko, 2013; Mitchell, 2008). Additionally, the resolution of prices and support policies assumes a critical role in this context (Butler & Neuhoff, 2008).

Globally, the three primary and widely employed RE schemes include feed-in-tariff (FiT), quota allocation, and more recently, competitive auction/tender systems (Hansen et al., 2020; IRENA, 2017; Kreiss et al., 2017; Toke, 2015; Yalili et al., 2020). Auction theory, as outlined by Klemperer (1999), is considered an applied branch of economics that explores the role of bidders in the auction market. This branch focuses on achieving optimal outcomes based on market forecasts.

The primary focus of this study is to evaluate the impact of a competitive auction scheme on the expansion of solar PV generation and the potential reduction (or stabilization) of Brent crude oil prices (i.e., West Texas intermediate oil price). This is particularly relevant given the shifting investment trends in the renewable energy sector, with a specific emphasis on seven open and dynamic economies within the European Union (EU). The significance of this investigation lies in recognizing crude oil as a crucial production factor, as any upward movement in its prices invariably results in increased production costs. These elevated costs are ultimately transferred to consumers through higher product prices, thereby creating inflationary pressures that dampen aggregate demand. Such economic repercussions can lead to a slowdown in overall economic activity (Naser & Rashid, 2018). As the popularity of renewable energy sources like solar grows, there is a potential decline in the need for crude oil. This could result in a decrease in hydraulic fracturing and crude oil production. While there were initial obstacles and expenses linked to the implementation of solar panels on Earth, progress in technology and widespread manufacturing has rendered solar PV systems more within reach and cost-effective (Sorokin et al., 2023). Consequently, this study contributes to existing literature by examining the gradual decline in solar PV generation auction price in relation to solar PV generation quantity, investments in the solar PV sector, and the global WTI crude oil prices across seven EU countries, namely Greece, Hungary, Italy, Poland, Portugal, Romania, and Spain. To conduct this analysis, we employ a panel vector autoregression (VAR) model, utilizing annual data spanning from 2000 to 2021.

The uniqueness of this paper lies in presenting details about our methodology and research concentration especially the relationship between the falling solar PV auction price and WTI crude oil price, along with offering policy recommendations and exploring the implications for the chosen countries. The structure of the rest of this study is as follows. The subsequent section offers the theoretical framework induces auctions and the literature review highlights specific articles with comparable methodologies, whereas Section 2 concentrates on the data and methodology. Section 3 delves into the result and discussion, and Section 4 presents the conclusions.

1 Theoretical background

Auctions are widely considered as an effective method for distributing subsidies related to renewable energy, providing valuable insights into the actual costs associated with renewable technologies (AURES, 2020). Connecting auction theory to the competitive market for renewable energy auctions, the price that satisfies the aggregate demand of winning buyers and covers the aggregate costs of the winning sellers is referred to as the market-clearing price. This clearing price ensures equilibrium in the energy market, where the aggregate quantity demanded equals the aggregate quantity supplied, a concept known in economics as market equilibrium (Morey, 2001).

Regarding the essence of auction theory, sellers aim to maximize their revenues, while buyers seek to acquire products at lower costs and thus the economic equilibrium appears. Auction theory is significant for both practical and theoretical reasons. Firstly, a substantial number of economic transactions are conducted through auctions. Secondly, auctions provide an excellent testing ground for economic theories due to their well-organized and straightforward economic environments. Finally, the auction process engages buyers and sellers in active and competitive interactions to determine the price (Klemperer, 1999). On this specific market, auctions have been instrumental in significantly reducing the installation costs of RE and have played a key role in the substantial decline in RE generation costs, experiencing an 85% reduction since 2010 (IRENA, 2021). This cost reduction is evident in the capital expenditures (CAPEX) for solar PV, where the investment cost per kW installed is notably lower (Diallo & Kitzing, 2020; Kost et al., 2021). The IEA (2019) emphasizes that engaging in competitive auctions expedites the reduction of costs for certain renewable technologies, such as solar PV. Setting targets and employing competitive auctions has the potential to facilitate the swift transition of solar technologies within the electricity sector (IEA, 2021).

According to Steffen (2020), there is a discernible trend indicating that solar PV projects encounter a smaller weighted-average cost of capital (WACC). Rennkamp et al. (2017) contend that solar PV can produce electricity with significantly shorter construction lead times when compared to large coal or nuclear power plants. To promote regional appropriateness, the use of domestically produced machinery and local planning has been encouraged within the context of solar PV. This approach is identified as a potential avenue for bolstering local employment and labor involvement (Sweeney, 2015).

Thus, it is essential to persist in the development of renewable energy alternatives, particularly solar energy, to pave the way for a sustainable energy future. This approach aims to diminish greenhouse gas emissions and diminish dependence on hydrocarbon-based energy sources. The transition toward solar energy is expected to bring about substantial transformations in the energy market, and it is imperative to factor in these shifts in any energy-related model or analysis (Ratner et al., 2022).

1.1 Literature review

The price of WTI crude oil directly affects prices of gasoline, diesel, and other oil products, influencing consumer and business costs. Fluctuations in WTI prices also impact inflation, currency exchange rates, and political stability in oil-dependent regions. Therefore, analyzing WTI prices helps businesses, investors, and governments make informed decisions and strategies, especially in uncertain markets (Sorokin et al., 2023).

Samour and Pata (2022) explore how U.S. interest rates and oil prices affect renewable energy use in Turkey from 1985 to 2016. They find that U.S. interest rates impact Turkey's renewable energy adoption via income and local interest rates. Turkey's economic ties to the U.S. amplify this effect, while oil prices hinder renewable energy through income-related factors.

Long et al. (2023) get a notable connection between renewable energy and oil. While elevated oil prices may stimulate investment in renewable energy, lower oil prices could lead consumers to prefer oil-based products. Additionally, minor fluctuations in global crude oil prices have the potential to induce substantial shifts in the investment patterns of Chinese renewable energy firms (Broadstock et al., 2012; Cao et al., 2020). Creating substantial investments and establishing robust support systems in renewable energy are essential components to drive increased generation of renewable energy (Sisodia et al., 2015a, 2015b). Mauleon and Hamoudi (2017) found that investments are important to reach economics of scales in RE deployment. So, any measure (like reduced installation costs) that incentivizes investment is desirable. Balashova and Serletis (2021) found in their research that oil price volatility, assessed through the GARCH-M(1,1) model, hinders total factor productivity (TFP) growth in both "old" and "new" EU countries. This, in turn, decelerates the rate of innovation and investment activity.

Lardic and Mignon (2006) and Rafiq et al. (2009) highlighted the substantial impact of oil prices (OP) on economic indices. This influence is diverse, especially when comparing oil-importing and oil-exporting countries. In the case of oil-importing nations, a rise in OP can lead to adverse effects on economic indicators. If these indicators decline, the ability to invest in infrastructure for renewable energy (RE) becomes constrained, hindering the allocation of necessary funds. On the contrary, an influx of funds into RE can expedite renewable energy generation, prompting consumers to shift towards options like solar PV. Consequently, the adoption of renewable energy is expected to rise, gradually replacing fossil fuels (Samour & Pata, 2022).

Ahmad (2017) and Dutta (2017) both support the idea of a substitution relationship between OP and renewable energy, suggesting that a rise in oil prices could result in an increased demand for renewable energy. Enhancing electricity production from renewable energy sources (RES) will diminish reliance on imported energy fuels like oil, promoting improved energy independence (Paska et al., 2009). Solar PV installations are highlighted as the most promising avenues for development in the upcoming decades (Paska et al., 2020).

The impact of regulatory frameworks on businesses and investments is crucial, with both positive and negative implications (Saltari & Travaglini, 2011; Schmit & Conrad, 2011). The renewable energy sector is currently experiencing significant growth and dynamism, making it an attractive investment option for companies and individuals seeking substantial returns. A notable example is the solar industry in the EU-27, where supportive schemes and a reliable regulatory environment are pivotal factors in fostering increased investments (Sisodia et al., 2016). In the context of private sector involvement in renewable energy investment in the Middle East, Aslani et al. (2012) highlight that friendly government policies and secure markets serve as driving forces for private firms venturing into this sector. The auction settlement has introduced a support policy that provides a stable environment for investing in solar photovoltaic (PV) systems, i.e., for the implementation of new renewable energy sources (Paska et al., 2020).

1.2 Theoretical model

To conduct the current study, the authors adopt the following theoretical framework to estimate the cost-effective solar energy in the seven open economies of the European Union.

$$\Delta AV_{SPV,i,t} = Const. + \propto_1 \Delta \ln SPV_{GEN,i,t} + \\ + \propto_2 \Delta SPV_{INV,i,t} + \propto_3 \Delta P_{WTI,i,t} + \varepsilon_t \quad (1)$$

where: $AV_{SPV,i,t}$ – the global auction value for the solar photovoltaic energy generation; $SPV_{GEN,i,t}$ – the quantity of solar photovoltaic electricity generation in the selected countries; $SPV_{INV,i,t}$ – the public investment in solar photovoltaic; $P_{WTI,i,t}$ – the West Texas intermediate oil price.

Incorporating the West Texas intermediate oil price to reflect fossil fuel pricing and provide a more comprehensive depiction of the global energy market environment and dependence is essential, considering that countries can function as either net crude or refined commodity importers. Within the European Union (EU), all member countries are actively transitioning their economies toward a greener path. In an effort to reduce greenhouse gas emissions and address environmental concerns, these nations are increasingly adopting solar photovoltaic technology for electricity generation while reducing reliance on fossil fuel-based sources, particularly oil. This shift is in line with the ambitious net zero emission target by 2050. Not even that shifting investment from fossil fuel (FF) to the solar PV projects is an important criterion for chasing the emission target by 2050.

To enhance the deployment of renewable energy (RE) and decrease reliance on fossil fuel-based electricity generation, countries are implementing the RE auction scheme. This is motivated by the global competitiveness of auction values compared to fuel-based electricity generation. For the purpose of the paper's theoretical model and quantitative analysis, specific EU countries (including Greece, Hungary, Italy, Poland, Portugal, Romania, and Spain) were chosen. These countries exhibit open economies, share close geographic similarities, and have been adopting the RE auction scheme in recent years as part of their efforts to achieve a net-zero target. Further, based on the net-zero targets, public investments are entering in this periphery. Based on our constructed theoretical model, we can anticipate that: (1) competitive auction values for solar PV will gradually increase solar PV generation ($\alpha_1 > 0$); (2) thereby more investments are coming into the solar PV market ($\alpha_2 > 0$); and (3) thereby positive effect on the alternative source of energy will support positively for stabilizing Brent crude oil pricing ($\alpha_3 > 0$).

2. Research methodology

2.1 Data

Since the emergence of renewable energy (RE), particularly solar photovoltaic (PV), there has been a noticeable increase in its adoption across selected countries starting in the 2000s. This surge in production has spurred a greater inclination towards consuming more renewable energy in these nations. In order to facilitate the robust deployment of RE at reasonable costs, countries began adopting auction schemes after 2012, with widespread implementation occurring predominantly from 2016 onward, although the global adoption of such schemes commenced in 2010. Linking with this pervasiveness public investment started to enter in this sector after 2010. The introduction and adoption of auction schemes for solar PV generation have led to a situation where the cost of energy generation from fossil fuels, particularly oil-based sources, is becoming competitive with auction prices. This study aims to assess how the decreasing auction values for solar PV impact solar PV generation and the global oil benchmark (i.e., WTI), examining whether the relationship is positive or negative. Also, the study wishes to verify the fund flows from the government end in the selected countries.

A yearly time series data from 2000 to 2021 have been researched, focusing on this time frame due to the establishment and robustness of renewable energy (RE) practices. A sample group comprising seven open economies from rather (semi-) periphery of the European Union (Greece, Hungary, Italy, Poland, Portugal, Romania, and Spain) was chosen to validate the proposed theoretical model (Equation (1)). To ensure a uniform load factor for planned solar generation potential, all selected countries were categorized based on similar climate positions. Furthermore, these nations adopted renewable energy auctions as a strategic approach for the resilient deployment of renewable energy resources.

The data pertaining to the energy sectors were sourced from the bp Statistical Review of World Energy, while auction value and investment data were obtained from the IRENA database (Tab. 1). It should be noted that the robust development of renewable energy (RE) commenced in the 2000s and continued thereafter. However, not all the countries in the sample embraced RE during this period, and the auction scheme was not consistently followed from the 2000s onwards. Consequently, due to the absence of data for certain periods and countries, the panel data can be characterized as unbalanced, a feature assessed through the panel VAR model. Conversely, it is essential to highlight that there is no presence of unit-root in the data. Additionally, the standard deviation and mean of the data remain time-invariant. This temporal constancy in the standard

Tab. 1: Data sources

Name of the variable	Source
Auction price/value for solar photovoltaic generation ($AV_{SPV,i,t}$)	IRENA Database (July 2022)
Solar photovoltaic generation quantity ($SPV_{GEN,i,t}$)	Bp Statistical Review of World Energy (July 2021)
Investment in solar photovoltaic sector ($SPV_{INV,i,t}$)	IRENA Database (July 2022)
West Texas intermediate oil price ($P_{WTI,i,t}$)	Bp Statistical Review of World Energy (July 2021)

Source: own

Tab. 2: Descriptive statistics and unit-root tests

	$AV_{SPV,i,t}$	$\ln SPV_{GEN,i,t}$	$SPV_{INV,i,t}$	$P_{WTI,i,t}$
Mean	0.062	0.177	13.032	61.298
Median	0.045	0.007	0.000	61.923
Maximum	0.195	8.890	429.145	100.062
Minimum	0.000	−25.039	0.000	25.932
Std. dev.	0.070	2.544	61.126	23.849
Skewness	0.698	−5.877	5.279	0.183
Kurtosis	1.965	66.042	30.989	1.854
Jarque-Bera	19.258	26,217.740	5,705.118	9.219
Probability	0.000	0.000	0.000	0.009
Unit-root test: Levin, Lin & Chu *t**				
(*P*)	0.000	0.000	0.000	0.000
Observations	153	153	153	153

Source: own (in EViews 10)

deviation and mean validates the stability condition of the VAR model (Tab. 2).

2.2 Method

One can assert that econometricians employ various econometric models to examine the influence of one variable on others. A contemporary model used for this purpose is the panel vector autoregression model (VAR). Panel VAR models aim to illustrate the dynamic interconnections within the data by imposing a limited set of constraints. Impulse response analysis or policy counterfactuals can be easily constructed, incorporating relevant exogenous shocks. The panel VAR follows the structure of a VAR model, assuming that all variables are endogenous and interdependent. However, it includes a cross-sectional measurement in addition to the depiction (Canova & Ciccarelli, 2013). Besides, the panel VAR model proves beneficial in assessing spillovers arising from unique interdependencies among countries, markets, and sectors (Jouida, 2018). It also aids in identifying shocks within endogenous variables. This approach treats all variables as endogenous and interdependent, encompassing both dynamic and static perspectives. This consideration extends beyond a set of predetermined or exogenous variables, incorporating a cross-sectional dimension (Somosi et al., 2024). The dynamic interpretation of a set of *N* time series variables, denoted as $y_t = (y_{1t}, \ldots, y_{kt})'$, can be succinctly defined by the basic VAR model form Equation (2).

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + \varepsilon_t \tag{2}$$

where: y_t – the model variables for the ($N \times 1$) vector; F_i – the matrix which contains ($N \times N$) autoregression coefficients; $\varepsilon_t = (u_{1t}, \ldots, u_{Kt})'$ – the unobserved error term vector with ($N \times 1$) Gaussian distribution where $\varepsilon_t \sim (0, E(u_t, u_t'))$ – a positive definite covariance matrix.

The determination of the optimal lag length in the model is accomplished through the utilization of criteria such as Schwarz (or Bayesian) information criteria (SC), Akaike information criteria (AIC), and Hannan-Quinn information criteria (HQ). These criteria are employed to assess the stability and asymptotic normality of the data. Subsequently, a test for the standardized condition is conducted to ascertain whether the modulus values are less than one. This condition indicates invertible explanations and the explanations of infinite-order vector moving averages (Kiss et al., 2020; Lütkepohl, 2005).

When constructing Equation (2), various parameter boundaries can be considered. Short-term constraints may be disregarded to elucidate the distribution of shocks in Cholesky's formulation, while long-term restrictions can be explicated by the shocks in Blanchard-Quah's formulation. To achieve this, our initial step involves acquainting ourselves with the structural representation of the VAR form in a condensed manner (Equation (3)), incorporating a time lag (ρ), and featuring three variables with structural coefficients *A* and A^s.

$$y_t = A_1^s y_{t-1} + \cdots + A_p^s y_{t-p} + Bu_t \quad \text{where: } \varepsilon_t = A^{-1} Bu_t \text{ and } S = A^{-1} B \tag{3}$$

We presume that specific coefficients hold a value of zero. The impact of u_{1t} is immediate on all other variables simultaneously, whereas u_{2t} influences only variables 1 and 2 concurrently. Similarly, u_{3t} exclusively affects the third variable in accordance with Cholesky's restriction (Equation (4)).

$$\varepsilon_t = Su_t = \begin{vmatrix} s_{11} & 0 & 0 \\ s_{21} & s_{22} & 0 \\ s_{31} & s_{32} & s_{33} \end{vmatrix} \begin{vmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \end{vmatrix} \tag{4}$$

In the approach presented in the extended restriction model by Blanchard and Quah (1989), the assessment of a shock's impact is limited to the row of the *F*-matrix corresponding to the position of the affected variable. The cumulative effect of the shock over time is presumed to be negligible, and ψ, representing the long-term multiplier ($F = \psi S$), is employed in the formulation (Equation (5)).

$$(1 - A_1 - \ldots A_p)^{-1} \varepsilon_t = \psi_{\varepsilon t} = F_{ut} \quad \text{and}$$
$$F = \begin{vmatrix} f_{11} & 0 & 0 \\ f_{21} & f_{22} & 0 \\ f_{31} & f_{32} & f_{33} \end{vmatrix}, \text{ while } S = \begin{vmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{vmatrix} \tag{5}$$

The *F*-matrix delineates the long-term possessions, and in the EViews 10 econometric program, its formation is influenced by the loading sequence of variables into the VAR model. This assumes the presence of a shock impacting each variable, with

Tab. 3: Structure of the *F*-matrix containing the long-term effects

Variables	Shocks			
	$AV_{SPV,i,t}$	$SPV_{GEN,i,t}$	$SPV_{INV,i,t}$	$P_{WTI,i,t}$
$AV_{SPV,i,t}$	f_{11}	0	0	0
$SPV_{GEN,i,t}$	f_{21}	f_{22}	0	0
$SPV_{INV,i,t}$	f_{31}	f_{32}	f_{33}	0
$P_{WTI,i,t}$	f_{41}	f_{42}	f_{43}	f_{44}

Source: own (in EViews 10)

the final variable in the sequence affecting only itself. The development of the *F*-matrix (Tab. 3) aligns with the theoretical model presented in the paper.

To identify stable and enduring connections among the variables, this study employs the Johansen test for co-integration. If the test fails to establish such a relationship, it does not conclusively demonstrate the absence of one; rather, it simply implies that a relationship may not be present (Dinh, 2019). The analysis of impulse response plays a crucial role in econometric studies, particularly in the context of the VAR model. In this analysis, the functions are interpreted as the impact of a unit shock on a specific variable within a given model, where the shock originates from variable *i* to variable *j*, all else being equal. Moreover, variance decomposition, for a specified time horizon, refers to the breakdown of prediction error variance. This decomposition process delineates the short-term and long-term effects of specific variables, representing the percentage of uncertainty in variable i^{th} attributed to the j^{th} shock after the *h* period (Dinh, 2020).

3. Results and discussion

The model utilized in this paper determined the lag length through the “lag order selection criteria,” wherein lags were constrained to 0–2 to fulfill the stability condition. The selection of the model was based on the AIC (Appendix, Tab. A1), indicating an optimal lag of 2 (with AIC at 19.55389, the lowest in the table). Consequently, the panel VAR exhibited no statistical errors at this juncture. Notably, the paper observed no inverse roots of the characteristic polynomial outside the unit circle, ensuring that all moduli were smaller than 1. This outcome further confirmed the stability condition of the VAR model (Tab. 4). The co-integration analysis (Appendix, Tab. A2) indicates the statistical significance of the independent variables at a 5% significance level. In the long run,

Tab. 4: Roots of characteristics polynomials

Root	Modulus
0.813638 − 0.269944i	0.857249
0.813638 + 0.269944i	0.857249
−0.033486 − 0.584658i	0.585616
−0.033486 + 0.584658i	0.585616
0.558431	0.558431
0.028578 − 0.173833i	0.176166
0.028578 + 0.173833i	0.176166
−0.138233	0.138233

Source: own (in EViews 10)

the independent variables exhibit a substantial impact on the dependent variable. This conclusion is drawn from the observation that all the values of the trace statistic and max-Eigen statistic surpass their respective critical values (Dinh, 2019).

Impulse responses (identifying cross-sectional dependence in a VAR model) prove challenging as the findings hinge on the impacts of individual variable shocks on auction value of solar PV, rather than centering on the model's coefficients, as is typical in most econometric approaches. Nevertheless, it is noteworthy that the residuals exhibit *a* notable degree of homogeneity (Appendix, Fig. A1) illustrate the impact of each variable's stimulus on the auction value of solar PV over time, along with 95% confidence intervals (±2 standard errors) as depicted in Fig. 1. To begin, an examination of the dependent variable, namely the auction value at the initial period, was conducted to determine whether the trend was increasing or decreasing. The analysis revealed a positive trend. Subsequently, the impulse responses of the remaining variables exhibited positive effects. This positivity suggests that the competitive auction value for solar PV accelerates the generation of solar PV in the selected EU countries. As the solar PV generation increases, these countries are likely to decrease their reliance on fossil-fuel-based sources for electricity generation. This reduction in dependence is influenced by the use of WTI oil price as a reference for spot price, future price, or the assessed price of oil, serving as a key global oil benchmark. Because the auction value is becoming the competitive of the Brent crude oil price. Further, the investment is found to be positive but not too significant which means that the investment is not sufficient yet for chasing the stipulated target within stipulated time span.

Finally, the analysis of variance decomposition is crucial, as it examines the percentage fluctuation in a time series attributable to the variables at the chosen time horizon and breaks down the forecast error variance for that specific period (Dinh, 2020).

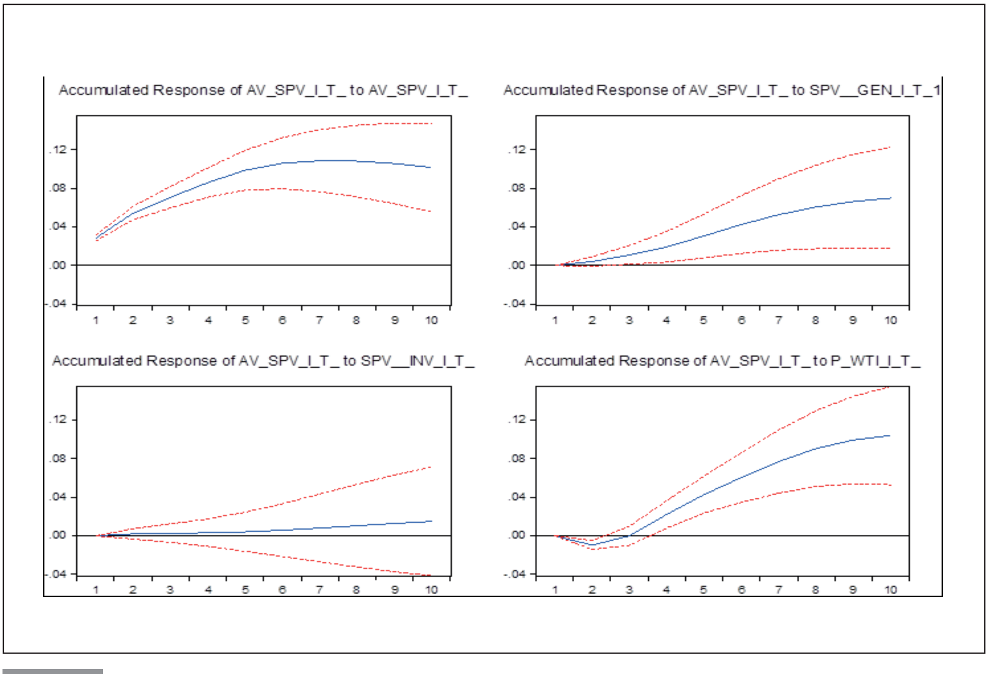

Fig. 1: Accumulated impulse response functions of auction value to model variables in long-run

Source: own (in EViews 10)

Tab. 5: Variance decomposition of $AV_{SPV,i,t}$ on VAR factors

Period	$AV_{SPV,i,t}$	$SPV_{GEN,i,t}$	$SPV_{INV,i,t}$	$P_{WTI,i,t}$
1	90.000	4.000	0.320	5.000
2	88.953	5.052	0.559	8.736
3	81.295	7.282	0.632	10.191
4	63.662	9.838	0.772	25.327
5	55.041	11.446	0.869	32.343
6	51.615	13.065	0.902	36.098
7	45.953	15.534	1.308	39.205
8	41.278	15.254	1.414	41.054
9	40.203	15.622	1.520	41.654
10	38.029	15.722	1.608	41.640

Source: own (in EViews 10)

Referring to Tab. 5, the variance decomposition of the auction value for solar PV indicates a significant contribution (~60%). Additionally, solar PV generation shows an above-marginal effect (~11%), while the WTI oil price demonstrates a relevant influence (~28%) and solar PV investment exhibits (~1%) marginal effect. These findings align with our primary assumption that competitive auction values for solar PV will gradually increase solar PV generation, thereby reducing dependence on oil-based electricity generation as an optimistic catalyst for stabilizing Brent crude oil prices.

Conclusions

To ensure a sustainable future and address global warming, as emphasized in the Paris Agreement (United Nations, 2015), it is imperative to focus on transitioning the energy mix to neutralized current and impending global environmental degradation. A comprehensive approach to the future of the energy sector necessitates the collaboration of leaders from major countries in formulating a framework that aligns with the evolving energy landscape. The implementation of an effective support scheme will serve as an additional catalyst for the smooth operation of the overall approach. Introducing an auction scheme in the solar PV market can contribute ensuring a desired quantity of energy at a lower cost, benefiting both buyers and sellers. This approach is poised to make the entire economy, including the energy sector, more profitable. An exemplary demonstration of this profitability is the global auction value competing favorably with the WTI oil price.

The current investigation employs a panel VAR model to analyze seven expanding and open economies (i.e., Greece, Hungary, Italy, Poland, Portugal, Romania, and Spain). The solar PV auction value serves as the dependent variable in this model. Utilizing the panel VAR model, the dependent variable is used to discern the impulse responsiveness concerning the variables under consideration. According to our study's results, the countries in our sample seem to be actively addressing climate change and striving to meet environmental objectives in line with the European Green Deal and the Paris Agreement.

We found a gap in the existing literature during our research. Subsequently, we selected seven growing and open economies from the EU to participate in the auction scheme as new practitioners. These countries were deemed appropriate subjects for investigating the potential of solar PV generation, investment scenarios in the solar PV sector, and the influence of WTI oil prices. Analysis of data for 22 years (from 2000 to 2021) for the selected countries revealed that the VAR model satisfied stability conditions.

After conducting our research, it was determined that the solar PV auction value has a significant impact on the relevant WTI oil price. This suggests that the auction value competes effectively with traditional oil-based power generation sources, such as gasoline, diesel fuel, and other oil products, which are directly influenced by the cost of WTI crude oil. Furthermore, our findings indicate that solar PV generation has a marginal effect, while the investment outcome has been noted to have an insignificant impact. Despite the increasing competitiveness of the auction value with WTI oil prices, insufficient public investment has hindered the ability of sample countries to expand their electricity generation from solar PV source. Additional endeavors are required to secure funding for emerging and developing economies, allowing them to expedite the implementation of clean energy. The recent COP28, led by the United Arab Emirates, signifies a significant advancement. It is imperative for nations to promptly translate these aspirations into reality by adopting tangible policies that facilitate a fair and impartial shift away from fossil fuels. This transition must be swift enough to uphold the Paris Agreement's objective of restricting global warming to 1.5°C.

In light of our research results, a pertinent inquiry emerges – how might the countries included in our sample confront the challenge of insufficient public investment? In addressing this query, it becomes apparent that governments of these countries could incentivize private investment, particularly through equity investment, fostering a mutually beneficial outcome for all stakeholders involved. Such a strategy not only aids in securing necessary funds but also cultivates a favorable perception within the community. Moreover, the EU itself can also dedicate funds to such projects as it did with the RRF.

Last but not the least, in the energy sector, the notion of "current or at this moment solution" is not pertinent; instead, it is closely associated with long-term strategizing. As a result, developed nations implement comprehensive energy plans over extended periods. Thus, maintaining coherent energy policies and ensuring effective management within this sector are imperative.

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Appendix

Tab. A1: VAR optimum lag selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−1,649.499	NA	38,144.46	21.901	21.981	21.933
1	−1,504.829	279.758	6,939.62	20.196	20.596	20.359
2	−1,440.319	121.331*	3,651.701*	19.554*	20.273*	19.846*

Note: * indicates lag order selected by the criterion.

Source: own

Tab. A2: Johansen co-integration test

Unrestricted co-integration rank test (trace)				
Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	0.05 critical value	Prob.**
None*	0.359	180.346	47.856	0.000
At most 1*	0.274	113.709	29.797	0.000
At most 2*	0.239	65.713	15.495	0.000
At most 3	0.152	24.781	3.841	0.000
Unrestricted co-integration rank test (maximum Eigenvalue)				
Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen statistic	0.05 critical value	Prob.**
None*	0.359	66.638	27.584	0.000
At most 1*	0.274	47.996	21.132	0.000
At most 2	0.239	40.932	14.265	0.000
At most 3	0.152	24.781	3.841	0.000

Note: Trace test indicates 4 cointegrating eqn(s) at the 0.05 level; max-Eigenvalue test indicates 4 cointegrating eqn(s) at the 0.05 level; * denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-Haug-Michelis (1999) *p*-values.

Source: own

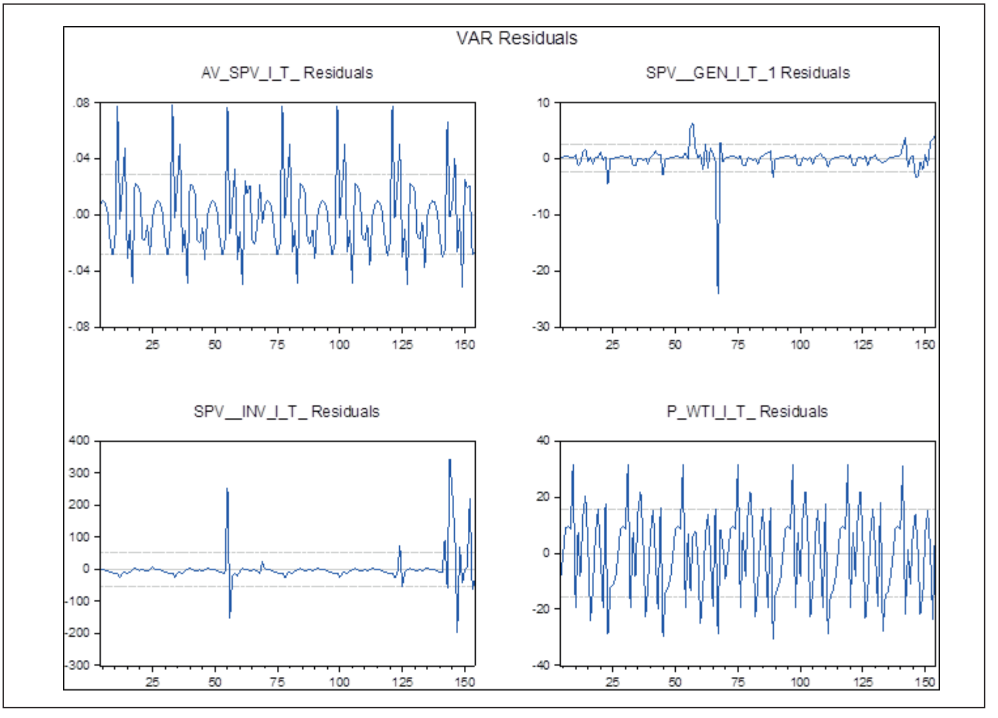

Fig. A1: VAR model residuals

Source: own