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Evaluating the Impact of Renewable Energy Policy Instruments on Capacity Expansion: Insights from the Visegrad Group Countries

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ABSTRACT

Renewable energy technologies have reached a pivotal point, demonstrating cost competitiveness with traditional energy sources and a continuing trend of affordability. Nevertheless, the successful deployment of renewable energy capacity crucially depends on the efficacy of renewable energy policy tools, casting a veil of uncertainty over their actual influence on the expansion of renewable electricity generation. This research delves into the array of policy instruments designed to bolster renewable energy capacity. Employing an econometric analysis, this study meticulously examines these policy tools, with a particular emphasis on feed-in tariffs, quotas, tenders, and tax incentives, seeking to facilitate the adoption of renewable energy within the Visegrad group countries, comprising the Czech Republic, Hungary, Poland, and Slovakia. Drawing from a comprehensive panel dataset spanning the years from 1990 to 2020, our findings unveil a nuanced perspective on the effectiveness of these renewable energy policy tools. Notably, our results underscore the varying degrees of success among different policy instruments, all of which significantly contribute to the advancement of renewable energy sources. A key revelation arises from the limited impact of quotas, a frequently employed regulatory measure, in stimulating the expansion of renewable electricity generation capacity. In contrast, feed-in tariffs, tenders, and tax incentives emerge as potent drivers in achieving this pivotal objective. This research sheds light on the dynamic landscape of renewable energy policy instruments, offering valuable insights for policymakers and stakeholders engaged in advancing sustainable and resilient energy ecosystems in the Visegrad group countries and beyond.

Keywords: Renewable Energy, Renewable Policy Instrument, Panel Data Models
JEL Classifications: O13, P18, P28, Q42, Q43

1. INTRODUCTION

In response to growing concerns about climate change and energy security, the utilization of renewable energy has seen a recent upsurge, particularly within the Visegrad Group countries, which are also known as the European Quartet, the V4, or the Visegrád Four (Sulich and Sołoducho-Pelc, 2021; Karatayev et al., 2023). During the period spanning from 1990 to 2020, renewable energy accounted for 10.2% and 28.6% of the total power generation in the V4 countries, respectively (IRENA, 2023). As ambitious targets for the expansion of renewable energy are being set, there is a mounting need for a thorough evaluation of policy measures associated with renewable energy (Księżopolski and Maśloch, 2021). For example, the European Union aspires to generate 40% of its electricity from renewable sources by 2040 (IRENA, 2023). The V4 countries have set the following targets: the Czech Republic aims to generate 25% of its electricity from renewable sources by 2025; Hungary has a goal of reaching 33% by 2020; Poland seeks to attain 32% of its energy consumption from renewable sources by 2025, and Slovakia aims for 30% of its electricity generation to be from renewables by 2030 (IRENA, 2023; Rákos et al., 2022). Achieving these objectives will be a formidable task, especially if the current suite of renewable energy policy tools and their impact on the expansion of renewable energy are not comprehensively examined (Godawska and Wyrobek, 2021; Kacperska et al., 2021).

Policy instruments play a pivotal role in advancing the adoption of renewable energy sources and driving the transition to a more sustainable and environmentally friendly energy landscape (Rokicki and Perkowska, 2020). These instruments are essential tools employed by governments and regulatory bodies to incentivize, promote, and regulate the deployment of renewable energy technologies (Bajan et al., 2021; Uğurlu, 2022). Here are some key policy instruments commonly used to facilitate the adoption of renewable energy:

1.1. Feed-in Tariffs (FITs)

Feed-in tariffs guarantee a fixed, above-market price for electricity generated from renewable sources (Lesser and Su, 2008; Alizamir et al., 2016). This policy provides long-term price certainty for renewable energy producers, encouraging investment in renewable projects (Jenner et al., 2013; Sun and Nie, 2015). FITs have been successful in jump-starting renewable energy industries in many countries. FITs are the most commonly employed policy tool in over 80 countries, including the V4 nations. Notably, by the end of 2020, it was projected that 87% of global photovoltaic (PV) capacity and 64% of wind capacity had been installed under FITs, making this the favoured renewable energy support program in EU member states (IRENA, 2023).

1.2. Quotas and Renewable Portfolio Standards (RPS)

Quotas and RPS policies mandate that a specific percentage of a region's energy must come from renewable sources (Yin and Powers, 2010; Tang et al., 2021). This creates a market for renewable energy and encourages the development of clean energy projects (Upton and Snyder, 2017). Non-compliance typically results in penalties, further motivating investment in renewables.

1.3. Tenders and Competitive Bidding

Tenders involve competitive bidding processes, where energy developers submit proposals to supply a predetermined amount of renewable energy (Toke, 2015). The winning bids secure long-term contracts for energy supply, providing both price certainty and competition to drive down costs (Bento et al., 2020).

1.4. Tax Incentives and Credits

Tax incentives, such as investment tax credits or production tax credits, reduce the financial burden on renewable energy projects (Cansino et al., 2010). These incentives can make investments in renewable technologies more appealing to businesses and investors (Ogunlana and Goryunova, 2017).

1.5. Net Metering

Net metering allows renewable energy system owners to feed excess electricity they generate back into the grid. In return, they receive credits on their utility bills (Poullikkas et al., 2013). This promotes small-scale distributed generation and encourages individuals to invest in renewable technologies like solar panels (Sunar and Swaminathan, 2021).

1.6. Green Certificates and Renewable Energy Credits (RECs)

Green certificates and RECs provide a market-based approach to promote renewable energy adoption (Ringel, 2006). Energy producers can sell RECs to consumers who want to offset their carbon footprint. This encourages investment in renewable energy projects (Adamczyk and Graczyk, 2020).

These policy instruments are not mutually exclusive and can be combined to create a comprehensive strategy for advancing renewable energy adoption (Fouquet, 2013; Thapar et al., 2016). The success of these policies often depends on local conditions, market dynamics, and the commitment of governments to sustainable energy transition (Karatayev et al., 2016; Pitelis et al., 2020). By designing and implementing effective policy instruments, governments can accelerate the transition to cleaner and more sustainable energy sources, contributing to a greener and more secure energy future (Carley et al., 2017; Song et al., 2022). In order to assess the effectiveness of four policy tools – feed-in tariffs (FITs), quotas, tenders, and tax incentives – within the V4 countries over a more extended timeframe than previously considered, this study adopts a comprehensive and all-encompassing methodology while applying an econometric framework. The research delves into the impact of renewable energy policy tools on renewable energy capacity by considering substitution factors (thermal/nuclear), economic indicators (GDP, coal/gas prices, electricity consumption), security aspects (energy/electricity imports), and environmental variables (carbon emissions). Standard panel data methodologies for econometric analysis are employed to assess the explanatory variables and policy tools affecting renewable energy capacity, as these variables may have associations with fixed regional factors (geographical or state-level) over time. This is elucidated in Section 2 of the report, which outlines the data and methodology utilized, encompassing model details and a comprehensive description of variable determinants. Section 3 will present the empirical findings and ensuing discussion, while Section 4 will encapsulate the conclusions and the implications for policy.

2. ENERGY SECURITY AND POLICY IN VISEGRAD GROUP COUNTRIES

The Visegrad Group, consisting of the Czech Republic, Hungary, Poland, and Slovakia, is a region of Central Europe with a growing emphasis on energy security and sustainable policy measures. Energy security is a central concern for these nations, as it entails ensuring a stable, reliable, and affordable energy supply while mitigating geopolitical risks and environmental impacts. Some energy security challenges include:

2.1. Diverse Energy Mix

The Visegrad Group countries have diverse energy portfolios. While coal and natural gas have historically played a significant role, there is an increasing focus on diversification through renewable energy sources (Karatayev et al., 2021). This diversification aims to reduce dependence on a single energy source and enhance energy security.

2.2. Geopolitical Vulnerability

These nations have experienced energy supply disruptions, primarily due to geopolitical tensions. To mitigate this vulnerability, they are working to enhance cross-border energy interconnections, establish energy storage infrastructure, and reduce reliance on external energy suppliers (Karatayev and Hall, 2020).

2.3. Environmental Considerations

The Visegrad Group countries are actively addressing environmental concerns related to energy production, such as air pollution and greenhouse gas emissions. Shifting toward cleaner and more sustainable energy sources is a crucial component of energy security and environmental stewardship (Wach et al., 2021; Muço, 2021).

These countries have faced significant energy security challenges throughout their histories and have implemented various policies to address these concerns:

2.4. Diversification of Energy Sources

Policymakers in the Visegrad Group are prioritizing the diversification of energy sources. This entails increasing the share of renewable energy in their energy mix while reducing reliance on coal and fossil fuels (Kochanek, 2021). Ambitious renewable energy targets are set to enhance sustainability and energy security.

2.5. Energy Efficiency

Improving energy efficiency is another core policy element. By implementing energy-saving measures in industries, buildings, and transportation, these countries aim to reduce energy consumption and minimize waste, thereby enhancing energy security (Dzikuć et al., 2021).

2.6. Regional Cooperation

Enhanced regional cooperation is vital for bolstering energy security. These nations are actively engaged in cross-border energy infrastructure projects, such as gas and electricity interconnectors, which enable the sharing of energy resources and provide backup in case of supply disruptions (Gostkowski et al., 2021).

2.7. Policy Support for Renewable Energy

Feed-in tariffs, tax incentives, and subsidies are some of the policy tools used to promote renewable energy adoption. By encouraging investment in renewable technologies, these policies contribute to a more secure and sustainable energy future (Chodkowska-Miszczuk et al., 2017).

2.8. Energy Independence

Reducing dependence on external energy suppliers is a significant policy objective. Developing domestic energy sources, such as renewables and shale gas, is viewed as a means to enhance energy security and decrease reliance on imports (Zapletalová and Komínková, 2020).

2.9. Environmental Initiatives

Policies addressing environmental concerns are closely linked to energy security. Stricter emissions standards, air quality regulations, and carbon reduction commitments align with the broader objective of improving environmental sustainability (Laszlo, 2023; Stadniczeńko, 2020).

The Visegrad Group countries are proactively addressing energy security challenges by implementing a multifaceted set of policies (Zholamanova et al., 2023). Diversifying their energy mix, enhancing energy efficiency, fostering regional cooperation, and supporting renewable energy sources are among the strategies aimed at ensuring a resilient, reliable, and sustainable energy supply while safeguarding against geopolitical and environmental risks. These efforts position the Visegrad Group countries at the forefront of sustainable energy security practices in Central Europe.

3. METHODS AND DATA

This study undertakes a comprehensive analysis of the relationships between the expansion of renewable energy and prevailing policy trends through the application of panel regression tests. To achieve this, a panel dataset is utilized, encompassing country-level data spanning the period from 1990 to 2020. The study employs a country fixed-effect model in conjunction with regression testing procedures to ascertain the robustness of the conclusions derived from the panel data model, considering all potential factors that may exert an influence on the test outcomes.

In order to address the issue of unobservable variations that remain constant over time, the study employs a fixed-effects estimator. This approach is instrumental in identifying unobserved variations and trends by representing each variable as a deviation from its mean value. In essence, the research seeks to investigate the extent to which both observable and imperceptible factors influencing the capacity of renewable power are correlated with the capacity of renewable electricity, employing panel data as the analytical framework.

Furthermore, the study treats unobserved sources of renewable heterogeneity as fixed effects, as they are presumed to exhibit relative stability over time. Panel data methodologies are subsequently applied to attain consistent parameter coefficient estimates, enhancing the accuracy and reliability of the results. This methodological approach facilitates the estimation of residuals in the regression, thereby aiding in the formulation of a rigorous test for the relationship between the capacity of renewable energy sources and unobserved variations.

The inclusion of a national fixed effect is deemed imperative to account for unobserved heterogeneity, which is known to exert a significant influence on the deployment and expansion of renewable energy sources. This rigorous approach ensures that the analysis captures and adequately addresses the multifaceted dynamics at play in the context of renewable energy capacity and policy trends. The estimation regression model is:

$$Y_{it} = \beta Policy_{it} + \delta X_{it} + \sum_{j=1}^{T-1} \tau_j T_j + u_i + \omega_{it}$$

Where Y_{it} is a measure of ratio of renewable electricity capacity in total electricity supply from non-hydro renewable sources in country *i* at year *t*; $Policy_{it}$ stands for the renewable policy instrument in use (FIT, quota, tender, and tax) in country *i* at year *t;* β is the coefficient of policy variables; X_{it} denotes the vector of explanatory variables; δ is the vector of coefficients of explanatory variables; T_j is a year dummy variable which is equal to one for year *j* and zero elsewhere; u_i is the country fixed effect index; and ω_{it} is the random error term that applies to each country at each year.

3.1. Data and Sources

Annual data for the V4 countries spanning from 1990 to 2020 was sourced from various outlets. The analysis considers the dependent variable, denoted as Y_{it}, representing the proportion of electrical capacity generated from renewable energy sources (comprising wind, solar, geothermal, and biomass, consolidated into a single metric) in GWh per year for each country and each year. It's important to note that hydropower is not encompassed within the measurement of renewable energy capacity, denoted as Y_{it}, as the policy schemes under examination in this analysis typically do not offer subsidies for hydropower. Data on renewable energy capacity is obtained from the International Renewable Energy Agency (IRENA).

3.2. Determinants of Variables

The hypothesis concerning the explanatory variables fortifies this research, with these variables being commonly encountered in existing literature. While the V4 countries exhibit diverse rates of economic growth, there are shared elements and uniformity in their policies. The choice of independent variables in this analysis, encompassing policy, economic, substitution, security, and environmental factors, was guided by the existing body of literature on the enactment of state energy policies. Table 1 provides a summary of the explanatory factors and the variables integrated into the model.

Key explanatory variables, namely Feed-in Tariffs (FIT), quotas, tenders, and tax incentives, are quantified at the country-year level and collectively form the set of renewable policy instruments, denoted as $Policy_{it}$. These data were sourced from the International Renewable Energy Agency (IREA). To represent the presence or absence of FIT, quota, tender, and tax incentives, binary dummy variables were constructed. In this binary coding scheme, a country that implemented any of these policies was assigned a value of 1, while those that did not were coded as 0. This approach effectively categorizes each of the four policy variables as having a value of 1 after the adoption of any policy instrument and as 0 prior to the implementation of such policies.

Table 1: Arguments depending upon variables

Variable	Dimension	Effect	Reason
Thermal	Substitute Variable	Negative	Substitute for RE
Nuclear	Substitute Variable	Negative	Substitute for RE
GDP growth	Economics	Positive	RE is a normal good
Electricity consumption	Economics	Positive	RE is a normal good
Gas price	Economics	Positive	Substitute for RE
Coal price	Economics	Positive	Substitute for RE
Energy import	Security	Negative	No need import as RE is sufficient
Electricity import	Security	Negative	No need import as RE is sufficient
Carbon dioxide emission	Environment	Positive	Pressure to minimise CO_2 emissions

It is noteworthy that some countries may choose to adopt multiple policies, while others may opt for a single approach. However, it is imperative to recognize that the definition employed here does not capture the nuanced diversity inherent to policy types, constituting a limitation of this method. Policy instruments can exhibit substantial variation across several dimensions. For instance, tax incentives may encompass measures such as reductions in tax rates, provision of tax credits, and specific stipulations regarding the eligible technologies qualifying for these tax credits. Furthermore, many countries administer tailor-made programs that focus on specific renewable energy technologies, such as photovoltaics, wind turbines, biomass energy, and waste-to-energy, within the framework of their utilization of tax incentives. Consequently, the simplistic binary representation employed in this study may not fully encapsulate the complexity and diversity of policy implementation across different countries and their various renewable energy initiatives.

3.3. Description of Explanatory Variables

3.3.1. Substitute energy sources

In light of the significant influence of conventional energy sources on the deployment of renewable energy, this study incorporates these variables into its analytical framework. The rationale behind this inclusion lies in the imperative role that environmental policies assume for governments, particularly in response to the considerable dependence on fossil fuel consumption within their respective national energy landscapes. Fossil fuels, while serving as a primary source of energy, give rise to a host of pressing environmental concerns, including but not limited to habitat degradation, air pollution, and contributions to the overarching issue of climate change. As such, this study postulates that the incorporation of substitution factors obtained from the International Renewable Energy Agency (IRENA) will serve to enhance the prospects for the expansion of renewable energy capacity. The underlying premise is that these substitution factors, which are rooted in the promotion of renewable energy as an alternative to environmentally detrimental fossil fuels, will play a pivotal role in driving the transition toward cleaner and more sustainable energy sources.

3.3.2. GDP effect

The examination of the renewable energy variable under consideration is a recurrent theme in the existing body of scholarly literature. Within this context, the capacity of wealthier nations to embrace and promote the adoption of renewable energy technologies, facilitated by their ability to bear the associated costs and offer financial incentives, emerges as a recurring topic of investigation. Conversely, there has been an argument positing that income, whether measured by real GDP or GDP per capita, does not consistently align with the potential for renewable energy expansion. However, it is pertinent to note that within affluent nations, financial resources indeed play a discernible role in fostering the adoption of renewable energy technologies. In light of the fact that the present study focuses on nations characterized by their prosperity, it is reasonable to expect that income levels will exert a positive influence on the enlargement of renewable energy capacity. To account for the non-stationary nature of GDP levels over time, this research adopts GDP growth as an explanatory variable, drawing data from the World Bank. By incorporating GDP growth as a measure, the study endeavors to capture the dynamic and evolving economic conditions of these affluent nations and assess their impact on the expansion of renewable energy sources.

3.3.3. Prices of gas and coal

The cost differentials between energy generated from traditional sources and renewable sources have long been a focal point of scholarly inquiry. In general, traditional energy sources tend to incur higher costs in comparison to energy derived from renewable sources. The shift from reliance on conventional energy sources to renewable alternatives is primarily propelled by the escalating economic burdens associated with fossil fuel-based energy production. This underlying premise establishes a positive correlation between the costs of conventional energy and the trajectory of renewable energy expansion. Empirical findings suggest that in nations characterized by rapid economic growth, the elevated prices associated with fossil fuel-based energy sources serve as a catalyst for augmenting the supply of renewable energy. In contrast, an alternative strand of research postulates that the adoption of renewable energy technologies can result in reductions in overall electricity expenses. The current analysis adds to this discourse by proposing that fluctuations in the pricing of fossil fuel-based energy sources could exert a significant influence on the growth of renewable energy capacity. For the purposes of this study, data pertaining to coal and natural gas prices is drawn from the International Energy Agency (IEA). The inclusion of these pricing variables serves as a foundational element for assessing the dynamics of renewable energy expansion and its interplay with the economic considerations related to traditional energy sources.

3.3.4. Dependency of energy security

Governments place energy security as a paramount policy concern, and empirical research has consistently underscored the significant influence of energy security considerations on the adoption of renewable energy sources. As such, this study examines energy security variables, specifically energy and electricity imports, as potential drivers motivating the adoption of renewable energy. Many nations are increasingly turning to renewable energy not only to curtail their reliance on imported coal, gas, and oil but also to bolster the reliability of their energy supply and mitigate the price volatility that often accompanies the importation of fossil fuels.

It is noteworthy that the commitment to renewable energy sources and the degree of responsiveness to their advancement exhibit an inverse relationship with the extent of a nation's energy imports. The imperative of energy security compels a strategic shift towards locally sourced and diversified energy supplies, with a notable emphasis on energy derived from renewable sources. As a quantifiable measure of energy security, this study employs the ratio of net energy imports to total energy and power consumption, utilizing data obtained from the International Renewable Energy Agency (IRENA) and Eurostat. This approach facilitates a comprehensive examination of the nexus between energy security considerations and the adoption of renewable energy, contributing to a more nuanced understanding of the dynamics underlying the transition to sustainable and secure energy sources.

3.3.5. Carbon dioxide emissions

Carbon dioxide (CO_2) emissions represent a pivotal environmental factor that plays a significant and multifaceted role within the context of renewable energy. The influence of carbon emissions on the adoption of renewable energy is particularly noteworthy, given that the escalation of CO_2 emissions exerts substantial pressure on political leaders and governments to address sustainability and environmental concerns. The imperative to combat climate change and mitigate environmental degradation has assumed a prominent position on the global policy agenda, making the role of carbon emissions within the renewable energy context a subject of critical importance.

One of the fundamental premises of this study is the hypothesis that higher levels of CO_2 emissions positively impact the deployment of renewable energy. This hypothesis is rooted in the recognition that the integration of renewable energy sources possesses the potential to substantially ameliorate global environmental conditions by mitigating CO_2 emissions. Data on CO_2 emissions used in this study is sourced from authoritative bodies such as the Energy Information Administration (EIA) and Eurostat, ensuring robust and credible empirical foundations.

The alignment between this hypothesis and the imperative of global energy policies underscores the continued prioritization of low-carbon energy solutions in the quest to combat climate change. It is therefore highly likely that the ongoing deployment of renewable energy will be further bolstered by climate change policies designed to actively curtail CO_2 emissions. Consequently, the study contributes to our understanding of the intricate interplay between environmental considerations, particularly CO_2 emissions, and the expanding domain of renewable energy within the broader context of sustainable and environmentally conscious energy solutions.

3.3.6. Summary statistics

Table 2 provides descriptive statistics for each of the renewable energy capacity metrics, including the mean, standard deviation, minimum, and maximum values for both the response and explanatory variables. It also presents a brief description of each variable along with its respective unit of measurement.

Table 3 presents the correlation matrix, and the correlation coefficients indicate the extent of multicollinearity among the explanatory variables.

Table 2: Variables definition and summary statistics

Variables	Unit of Measure	Mean	SD	Min	Max
Ratio of renewable electricity capacity	Natural logarithm of the contribution of renewable electricity capacity to total installed capacity	0.030	0.052	0	0.616
FIT (Dummy)	Feed-in-Tariffs as main policy for RES-E deployment	0.123	0.327	0	1
Quota (Dummy)	Quota as main policy for RES-E deployment	0.184	0.385	0	1
Tender (Dummy)	Tendering as main policy for RES-E deployment	0.203	0.402	0	1
Tax (Dummy)	Tax and subsidies incentives as main policy for RES-E deployment	0.224	0.416	0	1
Thermal energy	Share of thermal electricity generation (oil, gas and coal) from total	0.650	0.264	0.000	1.000
Nuclear energy	Share of nuclear electricity generation from total	0.192	0.210	−0.005	0.870
Energy import	The ratio of net energy imports to total energy consumption	0.242	0.302	−0.526	1.136
Electricity import	The ratio of net energy imports to total electricity consumption	0.024	0.141	−0.879	1.013
GDP per capita	Income per capita	3.202	18.640	−527.4	119.95
Electricity consumption	Tons of oil equivalent	4.15e	5.52e	158.334	3.47e
Coal price	Coal market price	28.795	23.928	0	149.78
Gas price	Natural market gas price	5.644	3.252	1.42	36.73
CO_2 emission growth	CO2 emissions per capita	−.016	0.795	−6.592	5.526

Table 3: Variable correlations

Variables	Crenel	Fit	Quota	Tender	Tax	Thermal
Crenel	1.000					
Fit	0.266	1.000				
Quota	0.030	−0.172	1.000			
Tender	−0.055	−0.126	−0.253	1.000		
Tax	−0.047	−0.157	−0.217	−0.279	1.000	
Thermal	−0.145	−0.116	0.028	0.079	−0.026	1.000
Nuclear	−0.079	0.038	0.046	−0.077	0.021	−0.642
Energy import	0.139	0.481	−0.148	−0.231	−0.187	−0.111
Electricity import	0.104	0.015	0.024	−0.022	0.020	−0.012
GDP growth	0.127	0.218	0.000	−0.071	−0.046	−0.022
Elect consumption	−0.150	−0.293	0.228	−0.020	0.068	0.105
CO_2 growth	0.004	0.007	−0.025	−0.019	−0.029	0.008
Coal price	0.352	0.549	−0.024	−0.209	−0.126	−0.113
Gas price	0.087	−0.004	0.398	0.015	0.061	0.044
	Nuclear	**Energy import**	**Electricity import**	**GDP growth**	**Electricity consumption**	**CO_2 growth**
Nuclear	1.000					
Energy import	0.028	1.000				
Electricity import	−0.170	0.223	1.000			
GDP growth	0.040	0.193	−0.027	1.000		
Elect consumption	0.054	−0.434	−0.087	−0.157	1.000	
CO_2 growth	−0.016	−0.022	−0.049	0.010	0.012	1.000
Coal price	0.043	0.593	0.040	0.218	−0.388	−0.053
Gas price	0.017	−0.233	−0.005	−0.068	0.176	−0.036
	Coal	Gas				
Coal price	1.000					
Gas price	0.142	1.000				

4. RESULTS AND DISCUSSION

4.1. Policy Instruments

Drawing upon the policy effectiveness estimates furnished within the purview of this analysis, it becomes apparent that there exists a discernible positive correlation between the capacity for deploying renewable energy and the presence of policy instruments such as Feed-in Tariffs (FITs), tender initiatives, and tax incentives. In stark contrast, quota-based regulatory frameworks for renewable energy, despite a growing reliance upon them, do not seem to exert a significant or demonstrable influence on the deployment of renewable energy. This empirical investigation suggests that the association between renewable energy capacity and quota-based policies is minimal, signifying potential challenges for the Visegrád Four (V4) nations in meeting their quota obligations within the renewable energy sector.

The efficacy of quota-based renewable energy policies may be intricately influenced by nuanced contextual factors. A salient consideration in this regard is the frequent coexistence of renewable energy policies with other concurrent energy policies. Given the V4 nations' notably high levels of energy consumption, concerted efforts aimed at enhancing energy efficiency may inadvertently diminish the dependence on fossil fuels, thus reducing the overall demand for renewable energy. This dynamic, in turn, may attenuate the impact of quota-based policies on renewable energy deployment. Consequently, it is crucial to recognize that the comprehensiveness of a quota-based policy cannot be exclusively assessed based on the stringency of the quotas themselves. Rather, other ancillary elements of quota-based policies, such as the presence of mechanisms for automatic compliance payouts or provisions for regional trade, may significantly contribute to the overall effectiveness of quota systems.

Table 4: Results from panel analysis

Variables	Coefficient	Standard Error
RE policy instruments		
FIT	0.02813***	0.00728
Quota	0.00293	0.00344
Tender	0.00757*	0.00397
Tax	0.00543**	0.00270
Substitute variable		
Thermal	−0.10771	0.06812
Nuclear	−0.17066**	0.07022
Security variable		
Energy import	−0.06778	0.07403
Electricity import	0.03516	0.02240
Economics variable		
GDP growth	0.00004	0.00002
Electricity consumption	−1.32e-1*	6.955e-1
Coal price	0.00011***	0.00012
Gas price	0.00077	0.00077
Environmental variables		
CO_2 emission growth	0.00060	0.00060

*P-value<the significance level of 0.1; **P-value<the significance level of 0.05 and 0.1; *** *P* value<the significance level of 0.01, 0.05, 0.1

Furthermore, the study's findings allude to the potential ineffectiveness of quota programs, which could be associated with issues related to deficient policy enforcement. These shortcomings may stem from ambiguously defined or inadequately structured policy requirements and a dearth of appropriate sanctions for non-compliance within the regulatory framework. These multifaceted factors underscore the complexity and nuances inherent to the evaluation of the effectiveness of renewable energy policies, and they warrant further investigation and policy refinement to enhance the efficacy of renewable energy deployment strategies within the V4 nations (Table 4).

4.2. Substitute Variable

The analysis reveals a discernible and statistically significant pattern within the energy landscape. Specifically, nuclear energy exhibits a notable negative relationship with the adoption and deployment of renewable energy sources, while other conventional energy sources, encompassing thermal energy derived from coal, natural gas, and petroleum, do not appear to exert any discernible influence on the capacity for renewable energy utilization. In summary, nuclear energy is found to have a statistically significant adverse impact on the adoption and deployment of renewable energy, whereas thermal energy from conventional sources does not exhibit any statistically significant impact on the utilization of renewable energy.

This observed antagonistic relationship between nuclear energy and renewable energy adoption may be attributed to their perceived competition within the energy domain. Nuclear energy is often positioned as a formidable competitor to renewable energy sources, primarily due to its potential to provide substantial solutions in the realms of environmental sustainability and energy security. This is substantiated by the fact that nuclear energy is commonly regarded as a nearly carbon-neutral energy source, which is pivotal in addressing environmental concerns, and it is often deemed a more cost-effective technology when juxtaposed with renewable energy sources. Thus, nuclear power emerges as a direct and substantial rival to the growth and prominence of renewable energy sources, signifying a complex interplay of policy and market forces within the energy sector.

4.3. Security Variable

The examination of energy security variables within the model does not yield a statistically significant impact on the deployment of renewable energy sources. This observation implies that energy security considerations do not constitute the predominant driving force behind the adoption and expansion of renewable energy sources. It is conceivable that this lack of significance may signify a shifting perspective among policymakers, who may be attaching reduced importance to energy security due to technological advancements that have unveiled previously untapped reserves of fossil fuels. However, it is essential to acknowledge that prior scholarly research has underscored the significant role of security considerations in catalyzing the development of renewable energy sources. For instance, the transition to renewable energy sources could inadvertently lead to an increased reliance on the importation of fossil fuels, necessitating the need for a secure and stable supply. Furthermore, the impetus for transitioning to renewable energy sources may be driven by a confluence of factors, including heightened energy and power dependencies, the cultivation of greater equity within financial markets, and the accumulation of human capital. These multifaceted dynamics within the energy sector warrant continued examination and inquiry, as they contribute to a nuanced understanding of the complex interplay of variables that underpin the adoption and proliferation of renewable energy sources.

4.4. Economics Variable

The impact of traditional energy prices on the adoption of renewable energy exhibits a divergent pattern within the scope of this study. The research findings indicate that gas prices wield a considerable and statistically significant influence on the utilization of renewable energy sources over the examined timeframe and across the countries included in the analysis. In contrast, the model suggests that coal prices do not exert a discernible effect on promoting the embrace of renewable energy sources. Several factors may contribute to the complex relationship between fossil fuel costs and the adoption of renewables. For instance, during periods characterized by rising energy costs, an increase in the utilization of renewable energy sources may lead to reduced electricity expenses, thereby making renewables a more cost-effective choice. Furthermore, the influence of fossil fuel prices on renewable energy sources may involve a more intricate theoretical explanation than a straightforward mechanism where higher fossil fuel costs automatically enhance the attractiveness of renewable options. It is plausible to consider that investing in renewable energy becomes more appealing when fossil fuel prices are elevated, and such heightened prices should stimulate the expansion of renewable energy capacity. Within the context of the Visegrád Four (V4) countries under examination, natural gas prices are revealed to have a statistically significant and positive impact on the adoption of renewable energy. Similarly, both coal and gas prices exert a statistically significant influence on the adoption of renewable energy, suggesting a multifaceted relationship. Conversely, income levels do not seem to exert a statistically significant influence on the deployment of renewable energy capacity within the given timeframe and set of nations. One plausible explanation for the observed lack of impact of income on renewable energy adoption could be the notion that economic growth often leads to increased demand, which, in turn, spurs greater manufacturing and higher energy consumption. The study's findings underscore the profound and varied environmental concerns among nations, which serve as compelling motivators for the adoption of renewable energy, contributing to a complex and multifaceted energy landscape.

4.5. Environmental Variables

The model employed in this analysis uncovers an absence of a discernible connection between carbon emissions and the utilization of renewable energy sources. Within this context, it becomes apparent that environmental concerns, particularly those related to carbon emissions, do not appear to function as a driving force in motivating the adoption of renewable energy sources. The outcome of this study suggests that the decision to transition to renewables, within the scope of the analysed data, was not significantly influenced by societal pressures pertaining to environmental quality or developments associated with climate change. This observation underscores the complexity and multifaceted nature of factors that inform the adoption of renewable energy sources and points to the need for further research to explore the interplay of these intricate dynamics.

The relationship between carbon emissions and the adoption of renewable energy sources is a critical aspect of contemporary energy and environmental policies. Carbon emissions, primarily in the form of carbon dioxide are a leading contributor to global climate change and air pollution. As such, reducing carbon emissions is a global priority to mitigate the adverse effects of climate change and enhance air quality.

Renewable energy sources, such as solar, wind, hydro, and geothermal power, are considered a sustainable alternative to conventional fossil fuels. These sources generate electricity with little to no direct carbon emissions, making them a crucial component in efforts to combat climate change. By shifting from fossil fuels to renewables, we can significantly reduce carbon emissions associated with electricity production. The connection between carbon emissions and the utilization of renewable energy sources can be summarized in several key points:

Carbon Emission Reduction: One of the primary motivations for adopting renewable energy sources is to reduce carbon emissions. Fossil fuels, including coal, oil, and natural gas, release substantial amounts of CO_2 when burned for energy generation. In contrast, renewables produce minimal to no direct carbon emissions during operation, making them an environmentally friendly choice.

Mitigating Climate Change: The transition to renewable energy is an integral part of global efforts to combat climate change. By reducing the carbon footprint of the energy sector, we can limit the warming of the planet and its associated impacts, such as more frequent extreme weather events and rising sea levels.

Clean Energy Policies: Many governments and regions worldwide have implemented clean energy policies and targets to reduce carbon emissions. These policies often include incentives and mandates to promote the use of renewable energy sources, creating a direct link between carbon emissions reduction goals and renewable energy adoption.

Energy Independence: Reducing carbon emissions by increasing the use of renewable energy sources also contributes to energy independence. It reduces reliance on fossil fuel imports, enhances energy security, and stabilizes energy costs.

Health and Air Quality: Beyond climate change, reducing carbon emissions through renewable energy adoption has significant co-benefits for public health. By decreasing air pollution associated with fossil fuel combustion, renewable energy helps improve air quality, reducing the prevalence of respiratory and cardiovascular diseases.

In summary, the connection between carbon emissions and the adoption of renewable energy sources is clear and essential. As societies worldwide continue to address the challenges posed by climate change and environmental degradation, the shift to renewable energy sources represents a vital step in reducing carbon emissions and fostering a more sustainable and healthier future for all.

5. CONCLUSION

This study employs a multifaceted analytical framework incorporating various explicatory variables, encompassing renewable energy policy instruments, income levels, energy and electricity consumption patterns, imports of energy and electricity, gas and coal prices, and carbon emissions. Its primary objective is to systematically evaluate the ramifications of renewable energy policy indicators on the expansion of renewable energy capacity within a selected group of Visegrád Four (V4) countries over the period spanning from 1990 to 2020. To substantiate its claims, the study adopts a composite methodology, combining a fixed-effects regression model with an intrinsic panel dataset encompassing diverse factors operating at the national level, as well as policy instruments.

The empirical findings of this investigation reveal a series of noteworthy policy implications. Notably, the empirical analysis underscores that the deployment of renewable energy capacity in V4 countries exhibits a positive and statistically significant association with Feed-in Tariffs (FITs), tenders, and tax incentives. Conversely, the study posits that quotas fail to yield substantive and meaningful outcomes, which suggests a fundamental lack of efficacy in achieving the intended policy objectives. An alternative perspective suggests that quotas may suffer from relatively lenient policy features that afford utilities the latitude to seek resources beyond national borders in fulfilling their renewable energy quota obligations. Consequently, the limited impact of quota-based measures is posited to be, in part, attributable to these inherent structural limitations. Notably, the study discerns that strategies grounded in pricing mechanisms prove to be more efficacious in driving renewable energy deployment when juxtaposed with those predicated on quantity-based policies.

The paramount significance of Feed-in Tariffs (FITs) in the context of fostering green energy sources is underscored, as this policy instrument emerges as particularly potent in augmenting the capacity of renewable energy. In contrast, the empirical evidence reveals that quotas exert no discernible influence on the expansion of renewable energy capacity. The study thus imparts significant credence to the notion that tax and tender incentives indeed hold promise in fostering the deployment of renewable energy within the context of the V4 countries. In summation, the application of a fixed-effects panel approach substantiates the pronounced and statistically significant influence of tax incentives, tenders, and FITs on the deployment of renewable energy capacity within the V4 countries, thereby contributing valuable insights to the discourse on renewable energy policy effectiveness.

The findings of this analysis yield a striking and noteworthy conclusion, revealing that various factors, including income, security considerations, gas prices, and carbon emissions, do not manifest as significant determinants of renewable energy deployment. Conversely, nuclear power, electricity consumption, and coal prices emerge as more potent and influential determinants of renewable energy deployment. This unexpected outcome underscores the greater salience of variables such as nuclear power, electricity consumption, and coal prices in shaping the trajectory of renewable energy deployment, vis-à-vis income, security concerns, gas prices, and carbon emissions.

The study further unveils a counterintuitive relationship wherein, due to the cost-effectiveness of conventional energy sources and the imperative to meet burgeoning energy demands, a negative correlation exists between power consumption levels and the deployment of renewable energy. In essence, the surge in power consumption exerts a hindrance on the expansion of renewable energy capacity. It is pertinent to highlight that the potential for renewable energy consumption in the current period is significantly contingent upon the capacity developed in the preceding period, underscoring the inertia within the renewable energy sector. Nevertheless, there is limited empirical evidence to support the assertion that societal awareness and efforts to curtail greenhouse gas emissions witnessed substantial progress during the timeframe examined.

Furthermore, it is noteworthy that income and gas prices did not undergo deliberate manipulation to incentivize the proliferation of renewable energy sources during the period under consideration, challenging the premise of concerted efforts driven by energy cartels to promote renewable energy. In light of these findings, it becomes imperative to deliberate upon the implications of the declining cost of renewable energy sources resulting from technological advancements, as this phenomenon may impose constraints on the pricing dynamics of gas. This critical issue necessitates meticulous scrutiny and further research to unravel its multifaceted implications for the energy landscape.

6. LIMITATION AND FUTURE RESEARCH

It is essential to acknowledge that the chosen dependent variable in this research study may be subject to certain limitations. Specifically, the study examines the percentage of power capacity derived from diverse renewable energy sources, including wind, solar, geothermal, and biomass. Different countries exhibit distinct preferences for specific types of renewable energy sources, with some nations heavily relying on wind energy, while others prioritize solar power. The inherent heterogeneity in the renewable energy portfolios of various countries introduces a challenge in controlling for these discrepancies effectively.

Moreover, the study employs dummy variables, which, while serving as a valuable simplification technique, may obscure the nuanced reality that the impact of policies can differ based on the specific technology and type of regulatory framework in place. Consequently, one limitation of the methodological approach adopted herein lies in its failure to account for the inherent diversity in policy types, such as variations in the intensity or level of feed-in tariffs or quotas. In essence, this approach does not fully accommodate the range of intricacies associated with renewable energy policy instruments and their implementation.

Future research endeavors may explore more comprehensive examinations of these distinctions, delving deeper into the intricacies of policy variations, and considering the inclusion of additional variables related to grid transmission, the interplay of overlapping policies, and the varying intensities of policy measures. These prospective research avenues would contribute to a more thorough and nuanced understanding of the factors influencing renewable energy deployment and policy effectiveness.

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