Renewable Electricity Generation and Regional Electricity Price Volatility in Sweden: Evidence from 2021-2025

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Abstract: The introduction of renewable energy into our energy markets has fundamentally changed the way energy markets behave. Within the current literature, there is a significant gap of information on how these new energy markets' shape regional price volatility. Using panel data from the four Swedish electricity price areas (SE1–SE4) over the period 2021–2025, this study combines GARCH volatility modelling with fixed-effects panel regression. By analysing regional variation in volatility within a shared institutional framework, the study contributes to the broader literature on renewable electricity generation, market stability, and the role of system-specific conditions in shaping electricity-price volatility.

Key words: Renewable energy, electricity price volatility, energy markets, regional electricity prices, Sweden, panel regression.

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For any errors, omissions, or shortcomings that remain, responsibility rests with the authors alone.

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1. Introduction

During the ongoing green transition, renewable electricity generation is expanding rapidly in order to meet set climate targets, which reshapes electricity markets and price formation. At the same time, there is strong public pressure and public debate about regional electricity price differences in Sweden, particularly regarding how the electricity system should be reformed and how price volatility should be managed (Mossige-Norheim and Wallbrandt, 2025; Expressen, 2026; Jerneck, 2026; Waters, 2025). This study therefore asks: *To what extent does renewable electricity generation shape regional electricity-price volatility in Sweden between 2021 and 2025?*

The aim of this study is to assess empirically how renewable electricity generation shapes regional electricity-price volatility in Sweden. By focusing on Swedish regions over a clearly defined period and using secondary quantitative data, the study aims to aid in understanding and shaping policy in the ever-changing energy landscape of the green transition.

The study contributes to the existing literature by examining electricity price volatility at the regional bidding-zone level, instead of focusing only on the national electricity market. Sweden being divided into four different electricity bidding zones (SE1–SE4) presents a useful case study for analysing how differences in renewable generation, electricity demand, and transmission constraints might influence price volatility across different regions. Particularly, the study separates wind power and hydropower due to their fundamentally different characteristics. While wind power is intermittent and dependent on weather conditions, hydropower is comparatively flexible and can be used to balance fluctuations in electricity supply and demand.

Methodologically, the study utilizes time-series volatility modelling combined with panel data analysis. To model monthly electricity price volatility, the study utilizes a GARCH(1,1) framework, before a fixed-effects panel regression is used to determine the relationship between renewable generation shares and regional price volatility over the examined period. By combining volatility modelling with a regional panel analysis, the study seeks to provide insight into how renewable energy expansion interacts with electricity market stability during a period characterized by substantial market uncertainty and structural transformation.

On the basis of the existing literature, the study hypothesises that renewable energy generation might lower electricity price volatility overall within the Swedish market. Specifically, hydropower likely reduces volatility due to its flexible and dispatchable nature, which allows it to balance supply with demand. On the other hand, windpower is expected to have an ambiguous effect on volatility due to its intermittent and weather-dependent nature. Overall, the study hypothesises that, in the case of Sweden, renewable energy share is associated with lower electricity price volatility.

2. Literature Review

Renewable energy and its effects on electricity prices have become one of the central topics in economic research, particularly in the context of the green transition. Electricity market dynamics are fundamentally changed by the expansion of variable renewable energy (VRE) (Mills, Wiser and Seel, 2021). Since renewable energy sources operate with very low marginal costs once installed, their growing share within electricity systems is raising questions regarding their impact on electricity prices and price volatility (Mills, Wiser and Seel, 2021; Hirth, 2013).

It is important to note that electrical price volatility is inherently different from any other form of market volatility. The reason for this is that electricity must be produced and consumed in real time and remains difficult to store at scale which makes prices highly sensitive to even small fluctuations between supply and demand (Bhattacharyya, 2011; Hirth, 2013; López Prol and Schill, 2021). As a result, electricity is what is called a 'time-heterogeneous good', meaning that its value depends on the specific time of production and consumption (Hirth, 2013). Furthermore, consumers typically do not respond to real-time price changes in their consumption of electricity which amplifies volatility by making demand highly price-inelastic in the short run (Sensfuß, Ragwitz and Genoese, 2008; López Prol and Schill, 2021). In addition, electricity markers suffer from periodic stability followed by high-volatility phases which can either be characterised by sudden spikes or even negative prices (Cifter, 2013; López Prol and Schill, 2021). The structure of the energy sector itself, specifically lumpy investment and indivisible generation capacity, further contribute to price volatility (Bhattacharyya, 2011). For instance, electricity markets such as the Nordic system frequently experience sudden price jumps and extreme price events that are not well captured by standard volatility models used for other assets (Cifter, 2013).

The structure of modern electricity markets developed historically under conditions that favoured centralised and continuously available electricity generation. Traditionally, electricity was treated as a natural monopoly due to the need for the large sunk cost associated with its transmission infrastructure as well as the aforementioned instant balancing between supply and demand (Akcura and Mutambatsere, 2024). As a consequence, electricity systems became dominated by vertically integrated utility models which integrated generation, transmission and distribution within a single entity and focused on large-scale investments such as coal, hydropower or nuclear energy (Joskow, 2008; Akcura and Mutambatsere, 2024). By 1989, 215 out of 230 economies operated under vertically integrated utility systems, supplying electricity to approximately 92 percent of the world's population (Akcura and Mutambatsere, 2024). Even after the liberalisation of the electricity market, supply was still focused on predictable and continuously available generation rather than intermittent or decentralised supply (Borenstein and Bushnell, 2015). This historical perspective matters as renewable energy enters a system that was originally designed for a different kind of energy mix and an entirely different form of production.

Importantly, changes in the mix of electricity generation are likely to have disproportionate effects on the market price. Within electricity price theory, the supply of electricity generation follows merit order from lowest to highest cost to meet demand as cheaply as possible (Bhattacharyya, 2011). This follows as electricity must be supplied instantly when demanded, which makes the most expensive electricity generator in use that supplies the quantity demanded the price setter (Bhattacharyya, 2011). The short-run marginal cost of this final unit therefore determines the market price (Bhattacharyya, 2011). This matters in the context of renewable energies, as research (Hirth, 2013; López Prol and Schill, 2021) shows that renewable energy has a near 0 cost in producing energy once it is set up. Following the theory, prices remain lower when renewable output displaces higher-cost generators from the price-setting position (Sensfuß, Ragwitz and Genoese, 2008; Hirth, 2013). Thus, the theory suggests that the mix of electricity generation, specifically the share of renewables, can have notable effects on the price.

When it comes to renewables, one could assert that theoretically renewable energy can keep prices lower in a more stable way. The reason for this (Bhattacharyya, 2011; López Prol and Schill, 2021) is that, under merit order, the cheapest supply of electricity is used first. As the literature (Hirth, 2013; López Prol and Schill, 2021) shows, this often means renewable energy, since its operating costs are generally the lowest. Normally, electricity prices fluctuate during the day as demand rises and falls, depending on which type of energy must be supplied within the merit-order system (Bhattacharyya, 2011). However, as long as renewable supply makes up a large enough share of the electricity system to meet day-to-day demand, it can keep higher-cost generators out of the price-setting position (Sensfuß, Ragwitz and Genoese, 2008; Hirth, 2013). The result is that electricity prices remain lower and may be less exposed to the usual merit-order volatility.

On the other hand, renewable energy might not be as reliable as other sources of energy due to their intermittency and non-dispatchable nature. While the operating costs of renewable energy is very low, many renewable sources cannot provide output continuously because their supply depends on weather conditions (Bhattacharyya, 2011; López Prol and Schill, 2021). This means that there must be a backup energy source to be used when renewable sources fail in providing energy (Bhattacharyya, 2011). Additionally, because renewable energy is non-dispatchable, they cannot be scheduled to be shut off or fired up when necessary as conventional systems would be able to (López Prol and Schill, 2021). This makes it difficult to create a meaningful schedule, and makes it harder to determine their market value (Bhattacharyya, 2011). Thus, the intermittency and non-dispatchable nature of renewable energy may itself become a source of electricity price volatility.

In that light, theory might suggest that renewable energy increases volatility. If renewable energy producers fail to supply the quantity of electricity demanded either due to high demand or a lack of proper weather conditions then more expensive backup plants may be needed (Bhattacharyya, 2011; López Prol and Schill, 2021). That can lead to sharp rises in the market price, as the price-setting unit shifts from low costs (renewable energy) to the high-cost alternative (Sensfuß, Ragwitz and Genoese, 2008; Hirth, 2013; Cifter, 2013). In the example of Europe (López Prol and Schill, 2021) one can observe that during energy droughts, there was a lack of proper weather which led to noticeably higher prices. Given this example, it has to be noted that renewable energy might bear the risk of increasing price volatility.

It should be noted that volatility only becomes a problem with renewable energy if there is no way of storing the produced electricity. The issue that renewable energy production experiences is the fact that there can be an overproduction while weather conditions are met and a lack of production when those conditions are not (Bhattacharyya, 2011; López Prol and Schill, 2021). On the one hand, Bhattacharyya (2011) states that electricity cannot be stored easily. It is noted (Bhattacharyya, 2011; López Prol and Schill, 2021) that electrical storage systems are too expensive, and are not worth their cost from an economic perspective, especially since renewables already have a large fixed cost (around 50% - 80% of the total cost of supply). On the other hand, Hirth (2013) notes that in Sweden's case, the country has successfully started to implement electricity storage systems, specifically its large hydro reservoirs which provide intertemporal flexibility, resulting in stable wind value factors that average 1.01 (or 101%), which could stabilise the aforementioned volatility effects. Thus, while electricity storage has a large infrastructural cost, in Sweden's case specifically, the country has started to change course.

A further point of consideration is that the impact of renewable energy on electricity prices depends on the structure of the electricity system. Mills, Wiser and Seel (2021) argue that electricity prices are influenced by structural characteristics such as generation mix, transmission capacity, and the market design itself. Sandberg (2024) provides empirical evidence from Sweden which shows that wind conditions have a strong and statistically significant impact on electricity prices across all 4 Swedish price zones. Importantly, transmission constraints can limit the ability to transfer electricity between regions which can lead to differences in prices and fluctuations across zones, which are not determined by renewables but by infrastructure and market structures (SNS Economic Policy Council, 2025; Kyritsis et al., 2017).

Another note of interest is the price volatility over long periods of time, attached to growing demand of electricity and how markets treat that demand increase over time. Since electricity supply cannot be expanded smoothly, markets have to either predict trends or risk sudden spikes in prices (Bhattacharyya, 2011). This is especially true for generation capacities that are added in large, fixed units such as coal plants or nuclear reactors (Bhattacharyya, 2011). According to Bhattacharyya (2011) nuclear plants have a construction time of 6 years and thus need to predict these trends far ahead of time. Bhattacharyya (2011) further claims that these predictions are notoriously inaccurate and most often do not work, which causes strong spikes in electricity prices. Solar farms, on the other hand, can be installed as quickly as 2 years while not providing the same price-disrupting supply as large energy plants (Bhattacharyya, 2011). This means that renewable energy sources can very well balance market prices theoretically without needing to predict many years ahead; however, there is a notable lack in the literature regarding whether this is true or not (Hirth, 2013; López Prol and Schill, 2021). The question thus raises itself whether renewable energy sources can reduce long-run volatility compared to supply predictions for large power plants.

While the long-term effects of energy supply composition on electricity-price volatility remain less clear, the literature also highlights the importance of external supply shocks within energy markets. When countries rely heavily on imported fossil fuels to meet domestic energy demand, domestic energy prices become increasingly dependent on developments in global commodity markets (Bhattacharyya, 2011). Historically, this dependence became particularly clear during the 1973 OPEC oil embargo, which increased Swedish energy prices by between 233% and 290% (Wickman, 1988; Melin, 2018). However, Sweden's exposure to oil price shocks has changed over time due to structural changes in the national electricity mix. Oil accounted for only 0.2% of Swedish electricity generation in 2024, while hydropower, nuclear power, and wind power accounted for the overwhelming majority of the total electricity production (Statistics Sweden, 2026). Therefore, the relationship between external supply shocks and electricity price volatility remains an important area within the broader theory of electricity pricing.

Despite these kinds of insights, existing research remains limited in their field of research. Much of the literature focuses on short-term price dynamics (e.g. Sandberg, 2024) or national-level outcomes (e.g. Tangerås, Holmberg and Le Coq, 2025). There is an important gap, as regions within the same country do differ in terms of generation capacity, transmission constraints, and their share of renewable energy. While renewable energy clearly affects price levels, its impact on long-term price volatility is less understood. Natural circumstances (wind and solar availability) can suggest that renewables increase volatility (Hirth, 2013; López Prol and Schill, 2021), yet this depends on existing market structures (Bhattacharyya, 2011; Hirth, 2013; López Prol and Schill, 2021). This study is addressing this gap by examining the relationship between renewable electricity generation and regional electricity price volatility in Sweden (2021-2025).

Overall, the literature suggests that the effect of renewable energy on electricity price volatility is theoretically ambiguous, because it interacts with several opposing effects within the market. On the one hand, the merit-order effect implies that low marginal cost renewable generation can reduce electricity prices and reduce volatility by displacing more expensive generators (Sensfuß, Ragwitz and Genoese, 2008; Hirth, 2013). It can also theoretically protect from drastic supply shocks and reduce reliance on energy supply from abroad (Bhattacharyya, 2011). On the other hand, the intermittent and non-dispatchable nature of renewable electricity increases uncertainty in supply, which can lead to strong spikes should renewable supply be low at that moment and demand must be met by using much more expensive generators (Bhattacharyya, 2011; López Prol and Schill, 2021). In addition, the impact of renewable energy on volatility heavily depends on the electrical system itself (storage capacity, transmission between regions) which can either help or hinder volatility (Mills, Wiser and Seel, 2021; Kyritsis et al., 2017). Empirically, for example, Hirth (2013) shows that renewable generation tends to lower average market prices while also increasing price volatility simultaneously in the short term. In the Swedish context, Sandberg (2024) finds that wind conditions have a statistically significant impact on electricity prices across all bidding zones. In that light, the literature suggests that the effect of renewable energy on volatility is theoretically ambiguous, suggesting that there might be a difference between short term fluctuations and large long term spikes.

3. Background

Sweden is a very fitting case study to analyse the relationship between the mix of renewable energy and regional electricity-price volatility. The literature review suggests that the effect of renewable energy on volatility is theoretically ambiguous and depends on market conditions. A suitable case study must therefore examine a system in which structural factors such as transmission capacity, generation mix, storage capacity and regional differences can be observed within the same market framework. Sweden exhibits these characteristics clearly. Since 2011, the Swedish electricity market has been divided into four bidding zones (SE1–SE4) due to transmission bottlenecks within the national electricity grid (Swedish Energy Markets Inspectorate, 2012). Sweden therefore provides a relevant setting for analysing regional electricity-price volatility.

Specifically, Sweden provides a fitting setting for examining how renewable generation interacts with transmission bottlenecks. Electricity-price volatility may be caused not only from renewable generation itself, but also from limitations in transporting electricity between different regions (Mills, Wiser and Seel, 2021; Kyritsis et al., 2017) . In Sweden, renewable generation (particularly hydropower) is concentrated mainly in northern bidding zones, while Swedish electricity demand is concentrated mainly in southern bidding zones (Svenska kraftnät, 2024). Due to the transportation of electricity, Sweden allows analysis of how renewable generation and transmission bottlenecks jointly shape electricity-price volatility.

Furthermore, Sweden provides a good case study on how differing forms of renewable generation are associated with volatility. The effect of the generation mix can only be properly assessed when there is variation in renewable-energy composition without major variation in institutions, currency, market rules and policies, as they can affect volatility themselves. In Sweden's case, the bidding zones operate within the same framework, the same market, the same currency and under the same policies. The major difference in the Swedish market is that northern bidding zones contain larger shares of hydropower generation, while wind-power expansion has occurred unevenly across Sweden (Sandberg, 2024; Svenska kraftnät, 2024).

Thus, Sweden provides a good case study on how differing forms of renewable generation are associated with volatility.

4. Data and Methods

In the case of Sweden, analysing the relationship between renewable energy share and regional electricity-price volatility requires a suitable empirical strategy. This suitable strategy must utilise data and methods that can capture the unique regional dynamics and market conditions identified in the background of this study. Since electricity markets differ regionally in Sweden's case, the study utilises sourced regional Swedish data from the ENTSO-E Transparency Platform together with a GARCH volatility framework and a fixed-effects panel regression model (ENTSO-E, 2016). This specifically helps analyse the relationship between renewable energy share and regional electricity-price volatility in the case of Sweden.

4.1 Data and Sample

Following the focus on Sweden, the study needs regional/ zone-level data. Research designs that seek to isolate how regional market conditions affect electricity-price volatility require prices to be observed separately across regions. Indeed, as the research question says, this study wants to understand regional price volatility based on its specific differences. Thus, the study uses zone-level electricity-price data from the ENTSO-E Transparency Platform (ENTSO-E, 2026). To be specific, daily day-ahead electricity prices (SEK/MWh) are used, which are the wholesale market-clearing prices that are established one day ahead of their delivery through the day-ahead electricity market (ENTSO-E, 2026). These prices are reported independently within each Swedish region and allow the direct observation of electricity-price fluctuations over time.

Daily day-ahead prices are the most suitable data for analysing electricity-price volatility. Suitable data must capture short-term fluctuations to estimate volatility, because volatility is the extent in which prices move over time (Ullrich, 2012). Daily day-ahead prices indeed capture these short-term movements, because they capture these movements daily (Ullrich, 2012). Specifically, they capture one high-frequency price observation each day. Meanwhile, monthly or annual averages are not capturing volatility in the same way as they smooth over many spikes (Ullrich, 2012). Therefore, the study does not rely on monthly or annual average electricity prices and instead estimates volatility from daily day-ahead prices before aggregating the resulting volatility measure to the monthly level.

The electricity-price data must be transformed into monthly variables. Variables can only be analysed properly within a methodological framework if the dependent and explanatory variables are measured at the same level of frequency. Daily variables cannot be matched directly with variables measured in months. In this study, the explanatory variables, including renewable production share and electricity demand, are measured monthly for each Swedish bidding zone, while electricity prices are measured daily. The electricity-price data must therefore be aggregated into monthly variables to ensure methodological consistency.

German electricity prices must be included in the empirical analysis. Variables capturing external pressure on the Swedish electricity market must be included to isolate the relationship between Swedish renewable energy production and Swedish electricity price volatility, because external market pressure might influence prices independently of renewable energy share. German electricity prices capture such external pressures, because Germany represents a major electricity market, which influences Swedish regional electricity prices (especially zones 3 and 4) through cross-border electricity trade (Energimarknadsinspektionen, 2015). Therefore, German electricity prices need to be included as a proxy to external market pressure.

The final dataset is structured as a balanced zone-month panel dataset. A balanced panel dataset requires observations which are consistently measured across all cross-sectional units and time periods, since both variations are necessary for a panel-data analysis. In this study, electricity-price volatility, renewable-generation shares, electricity demand and broader market-control variables are observed across four Swedish bidding zones for twelve months per year over a five-year period. This produces around 240 observations measured consistently across both regions and time periods. Wind power accounted for approximately 27.8 percent of electricity generation on average, while hydropower represented the largest renewable source with an average share of 42.0 percent (Table 2). As a result, the final dataset constitutes a balanced zone-month panel dataset.

This dataset is suitable for analysing electricity-price volatility, but it also contains several limitations. Suitable empirical datasets must capture a sufficient variation for a proper methodological analysis while minimizing bias and measurement limitations. The dataset used does capture substantial regional variation through the Swedish bidding zones, observed over 5 years (2021-2025). However, it also reflects a volatile timeframe which is defined by post-pandemic recovery, and the supply shocks caused by the Russian invasion of Ukraine (IEA, 2022). Additionally, transmission constraints and weather conditions might still affect volatility not captured by the data used. Finally, despite the panel structure, the number of observations does remain rather limited, resulting in a comparatively small sample size. All in all, the dataset is suitable for analysing regional electricity-price volatility, even though limitations persist which need to be addressed within the methodology.

4.2 GARCH Volatility Estimation

The methodology used in this study must importantly be capable of analysing electricity price volatility as a dynamic and time-varying process instead of a one-time measure of price variation. This develops directly from the research question which mandates examining the relationship between renewable electricity generation and electricity price volatility. To be specific, since the study focuses on volatility, the methodology must capture how this instability evolves in different market conditions over time. It must take into account the conditions of electrical markets which include spikes, persistent volatilities, as well as combine these conditions with the share of different renewable energy systems. Therefore, the methodology has to be able to analyse dynamic volatility in a time-varying process.

In addition, electricity price volatility must be treated as a dynamic process rather than as a fixed price variation level. This is because persistent processes are fundamentally dynamic, because their behaviour is evolving over time rather than staying constant. Electricity markets often demonstrate volatility clustering, where periods of instability follow periods of instability because of continuous market shocks and supply constraints (Cifter, 2013). Thus, electricity price volatility must be analysed by a methodology capable of modelling time-varying and evolving volatility patterns.

The methodology must further be capable of analysing electricity price volatility within a medium-run market context. This distinction is important because different time horizons in electricity markets reflect fundamentally different market dynamics. Short-run dynamics are typically associated with immediate balancing processes and daily or weekly supply-demand fluctuations, while medium-run dynamics capture periods of market adjustment involving fuel prices, renewable expansion and transmission pressures (Bhattacharyya, 2011). Long-run dynamics, in contrast, are more closely linked to structural changes such as infrastructure expansion, generation investment and broader market transformation (Bhattacharyya, 2011). The present study focuses on the period 2021–2025, which is treated as a medium-run adjustment period because it captures ongoing market instability and renewable expansion rather than long-run structural equilibrium or short-run daily movements.

Standard deviation provides an intuitive measure of electricity price volatility. This is because measuring the overall dispersion of electricity prices around their average level within a given observation period provides a straightforward way of identifying the degree of market instability (Cifter, 2013). Standard deviation captures precisely this overall price dispersion, and Cifter (2013) uses it within the Nordic electricity market to establish the existence of significant price fluctuations and unstable price behaviour before applying more advanced volatility models. Standard deviation therefore provides an intuitive baseline measure of electricity price volatility.

However, standard deviation is insufficient as the primary methodological framework for the present study. This is because the research question requires a methodology capable of analysing dynamic and time-varying volatility behaviour, volatility clustering and medium-run market adjustment processes within electricity markets. Although standard deviation provides an intuitive descriptive measure of price dispersion, even studies that initially employ standard deviation as a baseline volatility measure ultimately move toward more advanced volatility frameworks when analysing electricity markets (Cifter, 2013). For example, Cifter (2013) uses standard deviation to establish the initial volatility characteristics of the Nordic electricity market before applying Markov-Switching GARCH models, arguing that standard deviation alone cannot adequately capture non-normal price behaviour, volatility clustering or regime-dependent changes in electricity price volatility. Standard deviation is therefore insufficient as the primary methodological framework for the present study.

Furthermore, Ordinary Least Squares (OLS) regression is insufficient as the primary methodological framework for the present study as well. This is because a methodology designed to analyse electricity price volatility must be capable of modelling changing variance behaviour and time-varying instability within electricity markets. However, OLS primarily models the conditional mean of a dependent variable under assumptions of constant error variance, while electricity markets frequently exhibit heteroskedasticity and volatility clustering (Cifter, 2013; Weron, 2006) Consequently, OLS is insufficient as the primary methodology for analysing electricity price volatility within the present study.

The GARCH model on the other hand, is more appropriate for the present study because its underlying assumptions and variance structure are consistent with the dynamic characteristics of electricity price volatility. This is because a suitable methodology must be capable of analysing electricity price volatility as a dynamic, conditional and time-varying process within a medium-run market context while also incorporating volatility persistence and volatility clustering. The GARCH framework fulfils these requirements by specifying conditional variance as an autoregressive process in which current volatility depends on both lagged squared residuals and lagged conditional variance terms (Engle, n.d.). As a result, previous market shocks, past volatility states and ongoing market instability continuously influence current volatility estimates throughout the observation period, allowing the model to capture evolving volatility dynamics and clustered volatility behaviour over time. The GARCH model is therefore appropriate for analysing electricity price volatility within the present study.

Specifically, GARCH(1,1) is the right model in this case. This is because a suitable methodology must ensure that the model is able to balance the ability to capture persistent volatility dynamics with the practical limitations of the available dataset while avoiding unnecessary complexity. The GARCH(1,1) model is used as the standard benchmark model within volatility modelling because it captures volatility persistence effectively through a single lagged shock term and a single lagged variance term while avoiding unnecessary model complexity and overparameterisation, particularly in studies with limited observations (Cifter, 2013; Engle, n.d.). The suitability of the GARCH(1,1) model was further tested on our data. The estimated GARCH(1,1) coefficients indicate substantial volatility persistence across Swedish bidding zones (Table 1). According to Table 1, the combined Alpha and Beta terms were relatively high for each region (close to 1). This suggests that electricity-price volatility is time-varying and clustered over time, supporting the suitability of the GARCH framework for modelling electricity-price volatility. GARCH(1,1) is therefore an appropriate and methodologically sufficient specification for the present study.

Having established the suitability of the GARCH (1,1) framework for modelling electricity price volatility, the model is applied to daily day-ahead electricity prices for each Swedish bidding zone. The model is estimated separately for each bidding zone because Swedish electricity markets differ in generation composition, transmission constraints, and exposure to external shocks.

Specifically, for each bidding zone iii, the daily price process is first represented by the mean equation:

$$P_{i,t} = \mu_i + \epsilon_{i,t}$$

where $P_{i,t}$ means the electricity price in bidding zone i on day t and μ_i represents the average price level. Finally, $\varepsilon_{i,t}$ is the error term.

The error term is defined as:

$$\varepsilon_{i,t} = \sigma_{i,t} Z_{i,t}$$

Where $z_{i,t}$ is a random disturbance term with mean zero and constant variance.

The conditional variance is modeled using a GARCH(1,1) specification:

$$\sigma^2_{i,t} = \omega + \alpha\varepsilon^2_{i,t-1} + \beta\sigma^2_{i,t-1}$$

where σ^2i,t means the conditional variance of electricity prices. The parameters α measures the effect of new shocks on volatility, while β captures the persistence of past volatility. The model requires $\omega i > 0$, $\alpha i \geq 0$, and $\beta i \geq 0$ to ensure positive variance. A further condition, $\alpha i + \beta i < 1$, is generally required for volatility to remain stable over time rather than becoming explosive.

Aggregating the estimated daily conditional volatility series to monthly observations provides the most appropriate way to align the volatility estimates with the structure of the empirical analysis. This aggregation is necessary because the explanatory variables, including renewable electricity generation shares and electricity demand, are measured at the monthly level. Using daily volatility directly in the regression would therefore repeatedly assign identical explanatory values across daily observations while allowing the dependent variable to fluctuate on a much higher frequency. As a result, much of the observed daily variation would reflect short-term market noise and temporary shocks rather than variation in the explanatory variables themselves. Monthly aggregation therefore ensures consistency between the frequency of the dependent and independent variables while still preserving the underlying volatility dynamics estimated through the GARCH framework.

The daily conditional volatility estimates obtained from the GARCH(1,1) model are aggregated by calculating the average daily conditional standard deviation within each month:

$$Volatility_{i,m} = \frac{1}{D_m} \sum\nolimits_{t \in m} \sigma_{i,t}$$

where D_m is the number of days in month *m*. This produces one volatility observation for each bidding zone and month, which is then used as the dependent variable in the panel regression analysis.

4.3 Fixed-effects Panel Regression Framework

A fixed-effects panel regression framework is an appropriate method for analysing this relationship between renewable electricity generation and electricity price volatility across Swedish bidding zones over the given timeframe. The panel framework allows the study to analyse variation both across bidding zones and across time periods simultaneously. This is especially important because Swedish bidding zones show differences in structure such as generation composition, transmission capacity, and geographic conditions, while electricity markets are affected further by broader time-specific shocks including fuel prices, macroeconomic conditions, and policy changes. Furthermore, the fixed-effects model was supported empirically by the statistically significant F-test for unobserved zone effects ($p=0.0463$), indicating that regional heterogeneity is important and should not be ignored

(Appendix, B1). A fixed-effects specification thus helps isolate the relationship between renewable electricity generation and electricity price volatility by controlling for unobserved time-invariant regional differences as well as common temporal shocks.

A random-effects estimation can be considered, but is ultimately unnecessary for this study. The fixed-effects specification was considered more appropriate for the present study because Swedish bidding zones differ in several structural characteristics likely correlated with both electricity-generation composition and electricity-price volatility. These include factors such as hydropower availability, transmission conditions, infrastructure, and market exposure. Since the fixed-effects framework controls for such time-invariant regional heterogeneity, it is better suited for analysing within-zone variation over time. Additionally, a Hausmann test can be performed to test whether a fixed effects model or random effects model is more valid. Random effects are only considered acceptable if the p-value is above 0.10. The test found moderate support for the fixed effects model, evidenced by a p-value of 0.0707 (Appendix, B2). Due to these reasons and the Hausmann test not meeting the required p-value, a random-effects estimation is not necessary.

Therefore, the empirical specification is estimated as:

$$Volatility_{i,m} = \beta_0 + \beta_1 WindShare_{i,m} + \beta_2 HydroShare_{i,m} +$$

$$\beta_3 Demand_{i,m} + \beta_4 GermanPrice\, m + \alpha_i + \varepsilon_{i,m}$$

where $Volatility_{i,m}$ means the monthly electricity price volatility in bidding zone i and month m, estimated from the GARCH model. $WindShare_{i,m}$ and $HydroShare_{i.m}$ represent the shares of electricity generation from wind and hydropower, respectively. $Demand_{i,m}$ captures total electricity consumption in each zone, while $GermanPrice\, m$ represents the average monthly German day-ahead electricity price. It is included as a proxy for external market influences. A positive coefficient would suggest that higher German electricity prices are associated with higher Swedish electricity-price volatility.

Finally, the model employs Driscoll–Kraay standard errors, $\varepsilon_{i,m}$, as a means of obtaining robust statistical inference in the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence within panel datasets (Driscoll and Kraay, 1998). As reported in the Appendix, a Pesaran CD test was run, and the results indicate significant cross-sectional dependence between Swedish electricity bidding zones, supporting the use of Driscoll-Kraay standard errors within the empirical specification (Appendix B3).

The panel regression framework also shows little signs of heteroskedasticity. The Modified Wald test, a measure of heteroskedasticity, found no strong evidence that the error variance differs across Swedish bidding zones. The p value (0.5458) is far above the conventional threshold of > 0.05 (Appendix B4). The presence of heteroskedasticity would be a problem because it can make a regression's standard errors unreliable (Colonescu, 2024) . For instance, this could incorrectly cause variables to appear statistically significant. Due to the result of the Modified Wald test, it is conceivable that heteroskedasticity is not a problem in the model

The interpretation of these regression coefficients depends on both the fixed-effects structure of the model and the inclusion of electricity generation shares in the empirical model. Since electricity generation shares collectively sum to total electricity production, one category must be excluded from the regression to avoid perfect multicollinearity. The omitted category consists of all non-renewable sources as well solar. The reason that solar power is not included as its own separate variable within the regression framework is because its contribution to total Swedish electricity generation remained relatively limited during the sample period compared to wind and hydropower generation (Statistics Sweden, 2026). In addition, Swedish solar generation is highly seasonal and regionally concentrated, which makes its effects on electricity price volatility more difficult to isolate within the present empirical framework. The omitted category functions as the reference group against which the effects of wind and hydropower generation are interpreted.

As a result, the estimated coefficients primarily capture changes in electricity price volatility associated with changes in renewable generation shares within bidding zones over time. The coefficients of primary interest are β_1 and β_2. A positive β_1 would suggest that increasing wind generation shares are associated with higher electricity price volatility. In contrast, a negative β_2 would indicate that hydropower generation contributes to stabilising electricity prices. Thus, the interpretation of the regression coefficients depends on both the fixed-effects structure of the model and the inclusion of electricity generation shares within the empirical specification.

Although the panel regression does not establish definitive causal effects, the fixed-effects panel framework improves causal interpretation relative to simpler cross-sectional models. As discussed by Arel-Bundock (2026), statistical models may contribute to causal inference when the research design attempts to isolate relationships of interest while accounting for alternative explanations. By controlling for unobserved time-invariant differences between Swedish bidding zones, the model reduces the risk that the estimated relationships are driven by omitted regional characteristics such as geography, transmission infrastructure, or long-run differences in generation structure. The inclusion of relevant control variables, including electricity demand and German electricity prices, further helps isolate the relationship between renewable-generation composition and electricity-price volatility. Thus, the methodology allows the study to infer causality between renewable energy share and volatility.

5. Empirical Results

This section presents the empirical findings of the study. Electricity-price volatility was first estimated using GARCH(1,1) models for each Swedish bidding zone in order to examine volatility persistence and regional volatility dynamics during the 2021–2025 period. The estimated volatility measures were then incorporated into a fixed-effects panel-regression framework examining the relationship between renewable-electricity generation, electricity demand, broader European market conditions, and Swedish electricity-price volatility.

Overall, the empirical findings suggest that volatility within the Swedish electricity market was influenced more strongly by electricity demand and broader European market conditions than by renewable-generation composition itself. While hydropower displayed a potentially stabilising relationship with volatility, wind generation was not found to have a statistically significant positive relationship with electricity-price volatility during the examined period.

5.1 Electricity Market Developments and Volatility Patterns

Electricity-price volatility was first estimated separately for each Swedish bidding zone using GARCH(1,1) models based on daily day-ahead prices. The resulting daily conditional volatility estimates were then aggregated to the monthly level and used as the dependent variable in the panel-regression analysis. The GARCH results reveal considerable insights into regional volatility patterns.

Table 1. GARCH(1,1) Volatility Persistence Across Swedish Bidding Zones

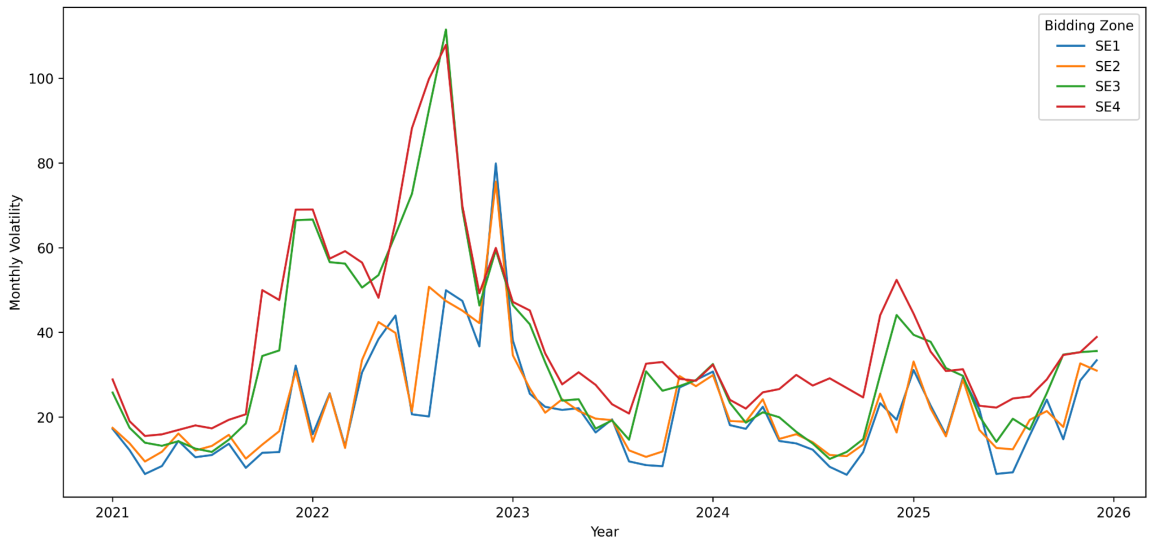
Zone	ARCH (Alpha)	GARCH (Beta)	Alpha + Beta	Interpretation
SE1	0.227	0.822	1.049	Highly persistent volatility
SE2	0.661	0.522	1.184	Strong shock-driven volatility
SE3	0.087	0.915	1.001	Near-integrated volatility persistence
SE4	0.079	0.920	0.999	Persistent but stationary volatility

Source: Author’s calculation based on data from the E-ENTSO Transparency Platform (2026).

The GARCH results show that volatility was highly persistent throughout the 2021-2025 period. Within the GARCH (1,1) framework, an Alpha+Beta score close to 1 indicates volatility clustering, meaning that volatility follows volatility. Indeed, the sum of the ARCH and GARCH coefficients were close to or slightly above 1 across the bidding zones ranging from 0.999 in SE4 to 1.184 in SE2. Therefore, Swedish electricity prices were characterized by persistent volatility clustering during the 2021–2025 period.

The bidding zones exhibit different types of volatility. The southern bidding zones, SE3 and SE4, show more persistent volatility, while SE2 is characterized by greater short-term price volatility. SE3 and SE4 exhibit a large Beta score, which measures on a scale that ranges from 0 to 1 how long volatility persists after the initial shock. SE3 exhibits a Beta of 0.915, while SE4 exhibits a Beta of 0.920. On the contrary, SE2 exhibits a Beta of 0.522, which is relatively low. In addition, the Alpha is a measure on a scale from 0 to 1 of how strongly current volatility reacts to new shocks. The results show that SE2 has an Alpha score of 0.661, while SE3 and SE4 exhibit a score of 0.087 and 0.079 respectively. Based on these results, one can ascertain that SE3 and SE4 are more prone to persistent volatility, and SE2 is more susceptible to greater short-term instability.

Figure 1. Monthly Electricity-Price Volatility Across Swedish Bidding Zones (2021–2025)



Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026)

Electricity-price volatility was highest during 2022 across all Swedish zones while normalising to pre-2022 levels in 2023 and 2024. Higher estimated monthly volatility values indicate greater instability within electricity prices over time. Figure 1 shows that volatility substantially rises in 2022 across all four zones relative to the other years in the sample period. Figure 1 shows that volatility falls to a lower level in 2023 and 2024. Swedish electricity-price volatility was therefore most significant during 2022 and less significant in the period following 2022.

It can be inferred that Sweden experiences transmission bottlenecks during the examined period. If transmission bottlenecks were not present one would expect volatility to be correlated between the different bidding zones perfectly, as electricity prices would flow to where they are needed, evening out prices. However, both Figure 1 and Table 1 infer drastic differences in monthly volatility fluctuations between the different bidding zones, meaning that Sweden likely experiences transmission bottlenecks which hinder electricity movement between the north and the south.

5.2 Descriptive Statistics and Correlation Analysis

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Monthly Volatility	240	28.93	18.49	6.40	111.47
Wind Share	240	0.278	0.155	0.069	0.637
Hydro Share	240	0.420	0.299	0.027	0.877
Demand	240	2855.28	2542.24	774	9523
Germany Price	240	118.91	77.19	47.16	465.18

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

Following from the GARCH model, the descriptive statistics of the panel regression find volatility to be high during the examined period, both within Sweden and in Germany. Standard deviation is considered high when it is large relative to its mean. In the case of Sweden, the standard deviation is about 64% of its mean, while it is about 65% for Germany. Thus, the panel regression confirms the results of the GARCH model that volatility was high in the examined period in Sweden and Germany.

Table 3. Correlation Mix

Variable	(1)	(2)	(3)	(4)	(5)
(1) Monthly Volatility	1.000				
(2) Wind Share	0.157	1.000			
(3) Hydro Share	-0.387	-0.301	1.000		
(4) Demand	0.218	-0.461	-0.626	1.000	

(5) Germany Price	0.675	-0.058	-0.007	-0.006	1.000

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

The correlation matrix suggests that hydropower is negatively associated with monthly electricity price volatility while windpower is slightly positively correlated. Correlation is measured on a scale between -1 and 1 with -1 showing total negative correlation and 1 meaning total positive correlation respectively. Hydropower and volatility are shown to have a moderate negative correlation of -0.387, while wind power is shown to have a slight positive correlation of 0.157. These findings suggest that hydropower contributes to stabilizing electricity prices within the Swedish electricity market while windpower causes a slight increase in volatility.

The correlation mix further suggests a clear link between German electricity prices and Swedish electricity price volatility. As was established, correlation is measured on a scale between -1 and 1. German electricity prices exhibit the strongest correlation with Swedish monthly electricity-price volatility among all explanatory variables included in the analysis. This suggests that Swedish electricity-price volatility is not only shaped by domestic electricity-generation composition, but especially by external market influences.

5.3 Fixed-effects Panel Regression Result

Table 4. presents the results from the fixed-effects panel regressions examining the relationship between renewable electricity generation, national electricity demand, external market influences, and monthly electricity-price volatility across the Swedish bidding zones. The results are notable and have implications on understanding Swedish price volatility.

Table 4. Fixed Effects Panel-Regression Results

Variable	Coefficient	Driscoll–Kraay Std. Error	t-statistic	p-value
Wind Share	3.349	23.043	0.15	0.885
Hydro Share	-22.359	42.467	-0.53	0.601
Demand	0.0043	0.0013	3.38	0.001***
Germany Price	0.162	0.0193	8.39	0.000***
Constant	5.721	27.656	0.21	0.837

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

The empirical results do not indicate that wind generation significantly shaped Swedish electricity-price volatility during the sample period. Although the coefficient is positive (3.349), the p-value is highly insignificant (p=0.885), far above the conventional threshold of $p < 0.05$. Therefore, the analysis does not show evidence to interpret a strong correlation of higher wind-generation and price volatility in Sweden between 2021 and 2025.

The empirical results do provide some support for the argument that hydropower reduces volatility. Hydropower exhibits a negative coefficient, (-22.359), which implies an association with lower volatility levels. However, the effect remains statistically insignificant after controlling for external market influences through German electricity prices, with a p-value of 0.601. Nevertheless, the negative direction of the coefficient remains meaningful and suggests that hydropower flexible and dispatchable characteristics may contribute to stabilizing energy markets.

The empirical results suggest that German electricity prices are the most significant variable associated with increased volatility. As seen in table 4, the p-value is equal to 0.000, which shows very strong statistical significance between German electricity prices and Swedish electricity price volatility. Therefore, the study infers that external market influence plays a significant role in shaping Swedish electricity price volatility.

Finally, the results of the empirical regression indicate that national demand for electricity influences Swedish electricity price volatility. With a p-value of 0.001, national demand for electricity is positively and statistically significantly associated with increased volatility of Swedish electricity prices. Higher levels of electricity demand appear to contribute to elevated levels of price volatility.

In sum, the empirical findings provide support for the argument that renewable-generation composition did not substantially increase Swedish electricity price volatility during the sample period. Instead, external market influence and electricity demand played far more significant roles in shaping Swedish electricity-price volatility across the Swedish bidding zones. As established previously, Arel-Bundock (2026), statistical models may contribute to causal inference when the research design attempts to isolate relationships of interest while accounting for alternative explanations, which the model does successfully. Therefore, the results infer a degree of causality, and the study does not find that renewable energy increases volatility.

6. Discussion

These empirical results do not support parts of the literature which argues that renewable energy increases electricity-price volatility. The literature review suggests that renewable energy production might statistically significantly increase volatility due to their intermittent and non-dispatchable generation which can create supply shortages if weather conditions are unfavourable leading to sharp increases in electricity prices (Bhattacharyya, 2011; López Prol and Schill, 2021). However, the panel-regression results show that the wind-generation coefficient remains statistically insignificant. There is no indication between a higher share of wind-generation and volatility during the same period. Therefore, the empirical findings disagree with some of the theoretical arguments.

6.1 Main Findings

This absence of a statistically significant relationship between volatility and wind generation might partially be explained by factors unique to Sweden. The literature review argues that intermittence creates volatility (Bhattacharyya, 2011; López Prol and Schill, 2021). However, in Sweden's case, wind conditions are favourable, exhibiting near constant wind speeds of up to 7–9 m/s, particularly in coastal and offshore areas (Chen et al., 2020). The intermittency of wind generation may therefore be less destabilising within the Swedish electricity system. Thus, the disagreement with parts of the literature might be due to factors specific to Sweden.

In that light, it seems as though the effect that renewable energy has on volatility strongly depends on regional factor endowments. If intermittence causes volatility (Bhattacharyya, 2011; López Prol and Schill, 2021) and factor endowments affect intermittence, then factor endowments must directly affect volatility as well. The findings show that different kinds of renewables have different effects on volatility (such as hydro decreasing and wind slightly increasing it). These depend on factor endowments and go in line with the indication that, in the Swedish case, favourable wind conditions in combination with hydropower availability mitigate the destabilising effects associated with renewables. Thus, the empirical findings suggest that the effect of renewable energy on electricity-price volatility is highly dependent on regional factor endowments.

On that note, the findings confirm the importance of transmission bottlenecks. The literature review suggests that volatility depends strongly on market conditions such as bottlenecks, and the background section supports the case of Sweden by noting the importance of bottlenecks in the establishment of the Swedish price regions (Mills, Wiser and Seel, 2021; Kyritsis et al., 2017; Svenska kraftnät, 2024; SNS Economic Policy Council, 2025). The findings confirm strong differences in volatility, especially between the northern and southern Swedish bidding zones which are likely caused by such bottlenecks (Figure 1). While this study does not analyse the case of Swedish transmission systems and their effect on volatility further, it does provide evidence that suggests that transmission bottlenecks remain a structural difficulty in Sweden.

Therefore, the empirical findings support the overall conclusion of the literature review, and expand its reasoning. The literature review suggests that renewable energy can both reduce and increase electricity-price volatility based on how merit-order effects, intermittency, storage capacity, and broader market conditions all interact (Bhattacharyya, 2011; Hirth, 2013; López Prol and Schill, 2021). In the Swedish case, it seems to support the theoretical ambiguity of the literature review, that the effects of renewable energy on volatility depend on case specific conditions. The analysis shows that market conditions, such as cross-border electricity demand, are highly significant when it comes to understanding volatility. At the same time, geographical conditions, factor endowments, might be more important than the literature review initially suggested. The study supports the broader argument that the relationship between renewable energy and volatility is theoretically ambiguous and depends on system-specific conditions.

The clearest cause for electrical price volatility in the period observed however remains external market influence, which is shown to be significantly more important than renewable energy. The literature already suggests that electricity price volatility is not determined solely by domestic conditions, but also by external shocks and interconnected energy-market dynamics (Bhattacharyya, 2011). The timeframe of this study coincides with the Russian invasion of Ukraine in 2022, restricting Germany's energy supply which relied on Russian gas at the time (IEA, 2022). When this situation generated substantial electricity price volatility, it had an effect on Sweden as well, which the empirical results strongly support. Not only was 2022 the year marked with the strongest spike in volatility (Figure 1), but German electricity prices exhibit the strongest relationship with volatility within both the correlation matrix and the fixed-effects panel regression, with a statistically significant p-value of 0.000 (Table 4). In contrast, wind generation shares remain statistically insignificant throughout the analysis. Thus, this study finds that Swedish electricity-price volatility between 2021 and 2025 was shaped more strongly by external market influences than any domestic renewable electricity generation itself.

In fact, these external shocks might be able to be mitigated by a higher production of renewable energy over the long run. The literature review argues that volatility partly emerges because the electricity market can struggle to adapt to changing demand conditions and external shocks (Bhattacharyya, 2011). This problem is particularly significant for large-scale conventional generation technologies such as nuclear power, which requires planning and construction over several years (Bhattacharyya, 2011). In the case of the price shock due to the Russian invasion of Ukraine, conventional energy sources might not be able to respond in time to reduce volatility in any meaningful way. In contrast, one advantage of renewable energy is that it can be implemented more swiftly if shocks occur (Bhattacharyya, 2011). Therefore, in light of the external shocks within the analysed timeframe, renewable energy could be a way to reduce volatility in a way that is more swift than for example nuclear power.

6.2 Policy Implications

Based on the study, one can recommend that Sweden should expand its renewable electricity generation. The Swedish electricity system possesses several structural characteristics that favor large-scale renewable electricity integration. In particular, Sweden benefits from abundant hydropower resources, strong wind conditions, relatively low population density, and substantial Nordic transmission integration. These factor endowments may improve the ability of the electricity system to absorb intermittent renewable generation while maintaining comparatively stable market conditions.

Additionally to that, based on the findings and its implications, it can be recommended that renewable energy systems should be paired with storage capabilities. The literature review already suggests that the problem some renewable systems face when it comes to volatility, is their lack of a storage system (Bhattacharyya, 2011; López Prol and Schill, 2021). The study confirms the literature by showing that hydropower, a system built on reservoir storage systems, reduces electricity price volatility. Therefore, volatility depends less on renewables alone and more on the system's ability to manage intermittency.

Consequently, one solution is to invest into storage systems such as batteries. Battery storage systems may improve the ability of electricity markets to integrate intermittent renewable generation by increasing system flexibility and balancing capability (Bhattacharyya, 2011; López Prol and Schill, 2021). For instance, while wind and solar generation remains largely weather dependent, electricity storage technologies can release stored electricity during times when renewable production inevitably falls. As a result, improving the storage capabilities of intermittent renewable energy systems would work to reduce volatility in an electricity system highly dependent on renewable energy.

6.3 Future Research

Future research should focus on less volatile periods in order to determine whether the observed relationships reflect long-term structural dynamics within electricity markets rather than the exceptional market conditions associated with the European energy crisis. The analysis focuses on a relatively short and highly unusual period characterized by exceptional volatility within European electricity markets following the post-pandemic recovery and Russia's invasion of Ukraine. Consequently, the estimated relationships may partly reflect crisis specific market conditions rather than long-term structural dynamics within electricity markets.

In addition, future research could integrate a cross-country comparison to assess the case specific factor endowments which influence renewable production effects on volatility that both Sweden and other countries possess. While the Swedish electricity system provides a useful case due to its favorable wind conditions (Chen et al., 2020) and substantial hydropower capacity, the findings may not necessarily be fully generalisable to other electricity markets abroad with different factor endowments. Comparative cross-country analysis may therefore help clarify how differences in market structure, transmission capacities, balancing systems and generation composition influence the relationship between renewable generation and electricity-price volatility.

Furthermore, future research should investigate the effect transmission bottlenecks have on volatility. The literature review and the background section argue that transmission bottlenecks are important (Mills, Wiser and Seel, 2021; Kyritsis et al., 2017; Svenska kraftnät, 2024; SNS Economic Policy Council, 2025) which is confirmed by this studies findings (Figure 1). However, there is no clear established relationship between volatility and transmission bottlenecks yet by this study. This provides fertile ground for a more comprehensive and detailed study on bottlenecks and their relationship to electricity price volatility, Future studies could also examine the role of electricity storage technologies in greater detail. The present findings suggest that system flexibility and the ability to manage intermittency may play an important role in shaping volatility outcomes within renewable-heavy electricity systems. Further research may therefore investigate whether investments in battery storage, reserve capacity, and other balancing technologies reduce electricity-price volatility as renewable-generation shares continue to increase as well as their economic feasibility within the electricity market.

7. Conclusion

The study does not find that renewable electricity generation meaningfully shapes regional electricity-price volatility in Sweden between 2021 and 2025. If renewable electricity generation was significant in shaping regional electricity price volatility, the results would find that hydropower and windpower generation would be statistically significant in determining volatility. Instead, it is external market influence that is the most important variable influencing Swedish electricity price volatility. National demand for electricity also shared a statistically significant, positive correlation with Swedish electricity price volatility. Therefore, the study answers the research question by explicitly finding that renewable energy does not increase or decrease volatility in a statistically significant way.

The hypothesis was partially correct and partially incorrect. The presented hypothesis is that hydropower significantly reduces Swedish price volatility, while the effect of wind power on volatility is more ambiguous due to intermittency. Contrary to this hypothesis, hydropower does not appear to significantly reduce volatility. Although hydropower generation exhibits a negative correlation with electricity price volatility, its stabilizing effect on volatility is not considered statistically relevant within the fixed-effects panel regression framework. On the other hand, windpower's effect on volatility largely matches the initial expectations. Wind power displays a slight positive relationship with volatility. However, its effect on volatility also remained statistically insignificant. As a result, while renewable energy production does not as expected significantly reduce volatility, it does not statistically significantly increase it either.

Furthermore, the study aids the literature by showing that the effect of renewable electricity generation on volatility depends on external influences and conditions such as factor endowments. The literature suggests already that the effect of renewable energy on volatility is rather ambiguous and depends on market structures such as storage systems, transmission constraints and other factors. However, the literature focuses mostly on intermittency and system structure, while placing less emphasis on how regional factor endowments themselves shape volatility. This study finds that external market influence as well as factor endowments might be significantly more important in explaining volatility than the share of renewable energy alone. In the case of Sweden, favourable wind conditions might mitigate the destabilising effects of intermittence. Thus, this study expands the current literature by shifting the focus away from intermittency alone to the importance of factor endowments and external influence in understanding electricity price volatility.

In addition, the case of Sweden proves to be particularly useful in analysing the effects of renewable energy production on electricity price volatility. As is established, volatility depends on multiple structural factors which requires a system that exhibits these factors and where effects can be isolated. Sweden, while having different price regions for electricity, also exhibits the same currency, the same institutions and same national policies. Meanwhile, the regions exhibit different mixes of renewable energies and factor endowments as well as being subject to transmission effects. This allows regional variables to be analysed without any major institutional distortions. Sweden, being close to Germany, is further able to show external effects on their internal volatility. All in all, Sweden as a case study is useful for analysing how renewable generation, regional factor endowments, transmission structures and external influences jointly shape electricity-price volatility

The methodology is valid and successfully implemented, ensuring reliability of the study's results. GARCH is the most appropriate method for measuring electricity price volatility. The electricity price data showed signs of volatility clustering, confirming the study's implementation of GARCH. Furthermore, the use of a fixed-effects panel regression is appropriate. Swedish electricity bidding zones exhibit different time-invariant regional differences, and the fixed effects framework controls for these differences, allowing the analysis to more accurately isolate the relationship between renewable electricity generation and electricity price volatility.

Numerous robustness tests, including a Hausman test, a Modified Wald test and a Pesaran CD test, further justify the chosen panel regression framework. Therefore, the study's methodology is valid and the results can be considered reliable.

In conclusion, the study argues that the effects of renewable electricity generation on electricity-price volatility must be understood within a case-specific framework. The empirical findings suggest that volatility depends strongly on external market influences, transmission structures, storage flexibility, and the interaction between regional factor endowments and the type of renewable energy used. In particular, the study finds that external market pressures play a substantially larger role in shaping Swedish electricity-price volatility than renewable-generation shares themselves. At the same time, the volatility effects associated with renewable intermittency appear to depend on broader system conditions and regional factor endowments. Thus, electricity-price volatility within renewable-heavy electricity systems cannot be understood through intermittency alone, but must instead be analysed in relation to broader market structures, regional conditions, and external market exposure.

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Appendix

Appendix A – Additional Regression Output

Appendix A1: Full Fixed-Effects Regression Output

Variable	Coefficient	Driscoll–Kraay Std. Error	t-statistic	p-value	95% Confidence Interval
Wind Share	3.349	23.043	0.15	0.885	[-42.760, 49.459]
Hydro Share	-22.359	42.467	-0.53	0.601	[-107.336, 62.618]
Demand	0.0043	0.0013	3.38	0.001***	[0.0018, 0.0069]
Germany Price	0.162	0.0193	8.39	0.000***	[0.1236, 0.2010]
Constant	5.721	27.656	0.21	0.837	[-49.618, 61.060]

Model Statistics

Statistic	Value
Observations	240
Number of Groups	4
Within R^2	0.569
F-statistic	54.74
Prob > F	0.000
Maximum Lag	3

Source: Author’s calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

Appendix B – Robustness Checks

Appendix B1: F Test for Fixed Effects

Test	Null Hypothesis	Test Statistic	p-value	Interpretation
F-test for unobserved zone effects	All bidding-zone effects are equal to zero (no fixed effects needed)	F(3, 232) = 2.70	0.0463	Reject H_0 at the 5% level. Fixed effects are appropriate because regional heterogeneity exists across Swedish bidding zones.

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

Appendix B2: Hausman Test

Test	Statistic	p-value	Interpretation
Hausman Test	7.04	0.0707	Moderate evidence supporting the fixed-effects specification

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

Appendix B3: Pesaran CD test for Cross-Sectional Dependence

Test	Null Hypothesis	Test Statistic	p-value	Interpretation
Pesaran CD test	No cross-sectional dependence between bidding zones	CD = 4.790	0.0000	Reject H_0. The results indicate significant cross-sectional dependence across Swedish bidding zones, suggesting that common shocks affect multiple regions simultaneously.

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).

Appendix B4: Modified Wald Test for Groupwise Heteroskedasticity

Test	Null Hypothesis	Test Statistic	p-value	Interpretation
Modified Wald test	Homoskedasticity across panels	$\chi^2(4) = 3.07$	0.5458	The null hypothesis cannot be rejected. There is no strong evidence of heteroskedasticity across Swedish bidding zones.

Source: Author's calculation based on data from the E-ENTSO Transparency Platform (2026) and Statistics Sweden (2026).