Climate Risk and Renewable Energy Markets: Evidence from Wholesale Electricity Price Volatility

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1. Introduction and Motivation

Climate change has increasingly been recognized as a systemic source of risk for both energy systems and financial markets (Battiston et al., 2021; IPCC, 2022). Renewable electricity generation is particularly exposed to physical climate risk because wind and solar output depend directly on meteorological conditions rather than dispatch decisions (Gernaat et al., 2021). As the share of renewable energy increases, electricity markets become more sensitive to weather-induced fluctuations in both supply and demand, raising concerns about short-run market instability (Joskow, 2019).

A growing literature documents how climate risks affect renewable energy equities and clean energy portfolios, often through changes in volatility (Engle et al., 2020). However, much less attention has been paid to the physical electricity markets in which renewable power is traded and priced. Wholesale electricity markets play a central role in allocating generation, balancing supply and demand, and revealing short-run scarcity through prices. Understanding how weather-driven shocks propagate through these markets is therefore critical for market design and risk management.

Existing studies on electricity markets either focus on average price effects (Mulder and Scholtens, 2013) or examine price volatility using realized generation (Badyda and Dylik, 2017), leaving the role of underlying weather-driven supply and demand shocks insufficiently explored.

2. Literature Background and Research Gap

Physical climate risk refers to the direct impacts of weather variability and extreme events on economic activity and infrastructure (IPCC, 2022). For renewable energy systems, changes in wind regimes, solar irradiance and temperature patterns directly affect generation potential, reliability and variability (Gernaat et al., 2021). These effects are particularly relevant in electricity markets, where non-storability and continuous balancing make prices highly sensitive to short-term disturbances.

A substantial literature examines the impact of renewable generation on wholesale electricity prices, primarily through the merit-order effect, showing that increased wind and solar output tend to reduce average prices by displacing higher-cost conventional generation (Mulder and Scholtens, 2013; Badyda and Dylik, 2017). A smaller body of work focuses on electricity price volatility and finds that higher wind generation is associated with increased volatility in systems with high renewable penetration (Ketterer, 2014). However, these studies typically rely on realized generation as the explanatory variable, which obscures the identification of underlying meteorological shocks and does not distinguish between supply-side and demand-side channels. In parallel, the climate finance literature shows that climate-related information is often reflected more strongly in volatility than in returns, but this evidence is largely drawn from financial asset markets rather than wholesale electricity prices (Jiang et al., 2025).

Overall, existing studies do not provide a unified framework that (i) identifies weather-driven supply and demand shocks and (ii) links these shocks to short-run volatility in wholesale electricity prices. This study aims to fill this gap by combining structural identification of weather effects with volatility modelling.

3. Research questions and conceptual framework

RQ1: How do weather and climate factors affect renewable electricity supply (wind and solar) and electricity demand?

RQ2: Do weather-induced supply and demand shocks amplify short-run volatility in wholesale electricity prices?

Conceptually, weather affects electricity markets through two simultaneous channels. On the supply side, wind speed, wind variability, solar irradiance and cloud cover determine the output of wind and solar generation (Staffell and Pfenninger, 2018). On the demand side, temperature affects electricity consumption through heating and cooling needs, commonly captured using heating and cooling degree days (Tanaka et al., 2022). When these effects occur unexpectedly and concurrently, they can generate short-run imbalances that increase price volatility, particularly in markets with high shares of renewable energy.

4. Research design and methodology

The empirical strategy adopts a two-stage framework that combines structural identification with volatility modelling.

In the first stage, a Structural Equation Model (SEM) is used to jointly estimate the effects of weather variables on wind generation, solar generation and electricity demand. This approach follows Tanaka et al. (2022), who use SEM to analyze weather effects on electricity supply, demand and price levels. Unlike their study, which focuses on average prices, the present research extracts structural shocks and uses them to examine price volatility.

In the second stage, these structurally identified shocks are incorporated into a GARCH-X model to assess their impact on wholesale electricity price volatility. Electricity price volatility is measured as the conditional variance of high-frequency price returns, consistent with standard practice in the electricity price volatility literature (Maniatis and Milonas, 2022). Wind supply shocks, solar supply shocks and demand shocks enter the variance equation as exogenous drivers. Positive and statistically significant coefficients indicate that the corresponding shocks amplify short-run market risk.

5. Data

The analysis uses high-frequency data from the Great Britain wholesale electricity market. Electricity prices, renewable generation and system demand are measured at a 30-minute settlement-period frequency. Weather data are obtained from the UK Met Office and aligned to the same temporal resolution. The sample period spans 2015–2025.

6. Expected contributions and relevance

This study makes three main contributions. First, it focuses on realized weather conditions rather than indirect climate or policy proxies, providing a physically grounded measure of climate risk in electricity markets (IPCC, 2022). Second, it introduces a structural framework that identifies weather-driven supply and demand shocks before linking them to wholesale electricity price volatility, improving causal interpretation relative to reduced-form approaches. Third, by concentrating on wholesale electricity prices rather than financial asset markets, the study generates insights directly relevant for market design, system operation and risk management in power systems with high renewable penetration.

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