International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02886
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

# Weather Derivatives as a Risk Mitigating Tool in Power Sector: A Systematic Literature Review

SUSMITA PATRA[1*] AND DR. GOURI PRAVA SAMAL[2]

[1*] Research Scholar (Ph.D.), P.G. Department of Commerce, Rama Devi Women's University, Phone No.- 9692389953, Email- papasusmita@gmail.com

[2] Assistant Professor, P.G. Department of Commerce, Rama Devi Women's University, Phone No.- 9439345301 Email- pravafinance@gmail.com

**Abstract:** The weather, be it temperature, rainfall, or wind has always been unpredictable and the frequency of unusual weather events has been rising. These weather changes can affect business in both direct and indirect ways, with the power sector being especially sensitive to weather conditions. Despite the fact that the catastrophic consequences of weather are widely known and have been extensively studied, the rising unpredictability of climate change has made the impact of non-catastrophic weather risks more prominent. To address this growing unpredictability, using weather risk management tools, such as weather derivatives, is becoming increasingly important. This study carries out a systematic literature review through descriptive and thematic analysis to assess the effectiveness of weather derivatives as a risk mitigation strategy in the power sector. The analysis shows that weather derivatives are an effective way to hedge the weather risk of various power sector participants. By offering an adaptable and flexible non-catastrophic weather risk management technique, it lessens moral hazard and unfavorable weather problems.

***Key Words-*** Weather risk, Weather derivatives, non-catastrophic, Hedging, effectiveness, Power sector

**JEL Classification-** G13, G32

## 1. Introduction

The weather is a crucial component that has a negative impact on world economies, having a considerable impact on either the revenues or costs of the companies, or both. Former US Commerce Secretary William Daley testified before Congress in 1998 that "weather is not an environmental issue; it is a major economic factor." The weather has a significant impact on at least $1 trillion of the $7 trillion US economy. Additionally, it is stated in the Economic Survey 2016–17 report that "estimates indicate that India currently suffers losses of roughly $9–10 billion yearly as a result of extreme weather occurrences. Of these, nearly 80% losses remain uninsured". According to a study, India has devastating monsoons about every five years, which results in a loss of up to 20% of GDP. This shows how essential it is to have effective planning for controlling weather risk in India's agriculture, electrical, mining, and construction sectors, among other industries that are most susceptible to the whims of the monsoon. The demand for electricity for end uses is sensitive to temperature variations in general, but heat waves in particular. The capacity of the generating and grid networks will be put under stress as a result of decreased generation output and efficiency as well as increased cooling demands from customers. The average yearly temperature has increased significantly during the past 20 years (2001–17). Since 1901, no previous 20-year period has seen a rise in average temperature as large as the one that occurred between 2001 and 2017 (together with temperature volatility) (RBI Bulletin Report, 2020). Risks associated with climate change were expected to cost Indian businesses Rs. 3,285 billion, while opportunities associated with climate change were worth Rs. 3,000 billion (CDP India Disclosure Report, 2021). According to researchers, climate risks indicate extreme events that are a direct threat to the livelihood of people and organizations. Unfavourable weather changes may have a negative effect on the organization's cash flows.

It's crucial to confront and manage these risks in order to lower the possibility of such events and the ensuing volatility in earnings. Although there are numerous models and techniques for climate mitigation, the unpredictability and uncertainty of extreme weather events still provide a challenge. Weather insurance is a common method of defending against extreme weather, however it has some restrictions when it comes to non-catastrophic weather. Weather derivatives, a novel tool for non-catastrophic weather risk management, offer important advantages over conventional management approaches.

The purpose of the current study is to evaluate weather derivatives as a special tool for managing weather risk and to assess the effectiveness of their use in the power industry, based on a study of prior studies. The reviews comprise three sections The literature on the effects of weather on the power sector is reviewed in the first part. The development of weather derivatives is examined in the second section. The usefulness of weather derivatives as a risk-mitigation tool in the electricity sector is examined in the third portion of the literature study. Concluding remarks are provided in the last section.

## 2. Method

In order to prevent biasness throughout the full assessment and summation of the body of literature, an SLR technique was adopted considering it an open, scientific, reliable, and evidence-based procedure. It provides reasonably lucid conclusions after reviewing pertinent literature, assessing contributions, analysing and synthesising data (Deyner & Tranfield, 2009). The SLR follows a specific approach in order to identify trends, themes, variables, and the intellectual elements of the topic. However, the structure suggested by (Tranfield, Denyer, & Smart, 2003) and (Deyner & Tranfield, 2009) has been used by the writers of this research. The framework is composed of five main stages: formulation of the question, identification of the literature, selection and assessment of studies, analysis and synthesis, and reporting and application of findings. A series of review techniques are reviewed in order to better utilise the SLR results and explain the review questions.

The SLR stages will now be covered one by one in this section.

### *2.1 Questions formulation*

This SLR covers two key review questions considering the study's purpose:

RQ1. Is energy sector sensitive towards extreme weather conditions?

RQ2. Are weather derivatives effective in hedging the weather risk in energy sector?

### *2.2 Locating studies*

Subsequently different literatures were explored for the pertinent studies. The objective of this stage was to gather and evaluate as much pertinent data as feasible. The keywords, phrases, strings, and database were to be decided at this point.

As can be seen in Table 1, several search terms were used to find papers employing various nomenclatures. The search strings were created using the search terms and Boolean operators. The papers were then searched for using these search terms on five different search engines such as Scopus, Springer, Web of Science, Emerald, and ProQuest.

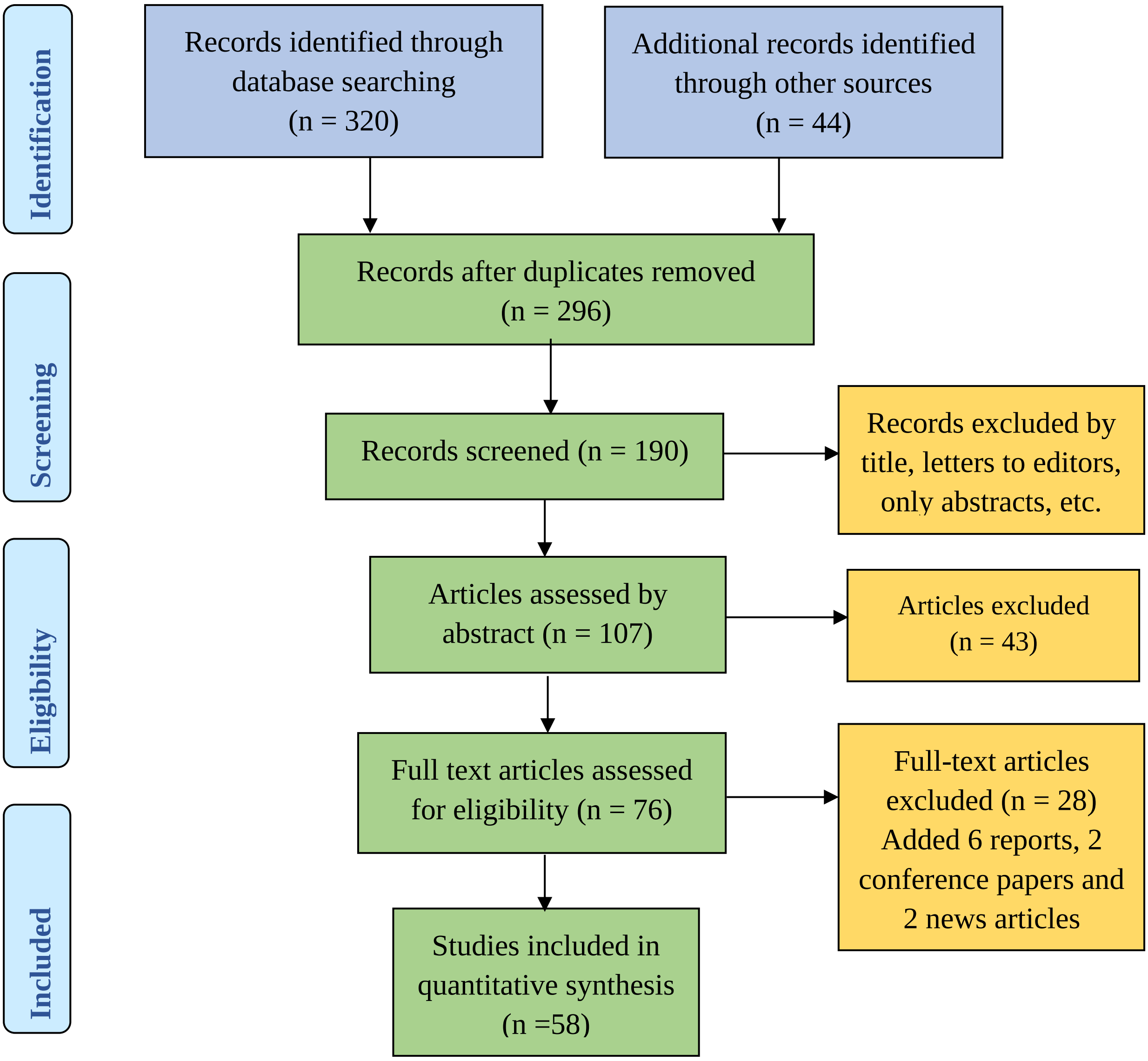
International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02886
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

After database searches and duplicate elimination, 364 papers were picked for further analysis.

**Table 1- Database search string.**

| | |
|---|---|
| **Keywords (String)** | "weather derivatives*" OR "weather futures*" OR "temperature derivatives*" OR "power sector*" OR "climatic conditions*" OR "hedging*" OR "risk hedging*" OR "power*" OR "energy" OR "derivatives*" OR "Pricing*" OR "Modelling" OR "Effectiveness" OR "India" OR "instrument*" OR "factors*" OR "CDD*" OR "mechanism*" OR "HDD*" OR "monte-carlo*" OR "simulation*" OR "temperature*" OR "time series*" OR "participant*" OR "model*" OR "volatility*" OR "Insurance" OR "econometrics*" OR "stochastic*" OR "basis risk*" OR "index*" OR "dynamic hedging*" OR "wind power*" OR "China*" OR "willingness to pay*" OR "sensitivity analysis*" OR "prediction errors*" OR "price dynamics*" OR "burn analysis*" |

**Fig. 1. PRISMA Model**



### *2.3 Study selection and evaluation.*

Weather derivatives is an area of investigation with many divergent studies with different perspectives. So, the authors did not further limit the quantity of papers by modifying the keywords. On the contrary, inclusion and exclusion standards and quality evaluation were employed to weed out the studies. Making a determination of each paper's applicability in light of the review questions using specific criteria was one of the most crucial tasks. Figure 1 depicts the complete procedure for choosing existing literature for further analysis as per Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) model.

The first step involves collecting records from database searching and other sources. A total of 364 articles were collected. Followed by this, the next step involved removal of duplicate

records which got reduced to 296 records. The selected records were then screened and 82 records were removed based on title, letters to editor, only abstracts, etc. In the next step, abstracts were reviewed for 107 selected articles which resulted in exclusion of 43 articles. Three different forms of relevancies form the basis of the abstract review: Papers should address the impact of weather on energy sector, secondly, evolution of weather derivatives and lastly, papers must be related to effectiveness of weather derivatives in power sector (including pricing, modelling, and effectiveness for power sector that can generate financial gains). This step reduced the number of full-text papers to 76. Followed by these the full text papers were assessed for robust quality assessment. The quality assessment is based on the criteria that only the publications that able to contribute to answering the research questions, and aligning with it were selected to be taken forward. Finally, a total of 58 publications were selected for further analysis and synthesis focusing on the objectives of the study for complete review which includes 6 reports, 2 conference papers and 2 news articles. These were added because they were revealed as relevant to the research but were not found in the initial literature search.

### *2.4 Analysis and Synthesis*

In the next stage the descriptive and thematic content of each chosen publication was examined. The descriptive analysis focuses on categorising publications by year, publication by type, country of publishing, database source, etc. and is more deductive in character. Thematic results and thematic synthesis make up the two elements of the thematic analysis, in contrast. The literature is identified and categorised according to thematic findings into constructs relevant to the study topics.

### *2.5 Presentation and utilisation of the results*

This study is focused on conveying the results in three different ways: descriptively, conceptually and as a theoretical foundation (thematic) for weather derivatives.

## 3. Descriptive Results: Summing up the Weather Derivatives Literature

To determine the type of publication, year of publication, database source, and authors' locations, the 58 articles discovered by the SLR were analysed. The major goal of this analysis was to recognise the patterns in this corpus of material that were pertinent to RQ1 and RQ2.

48 of the articles found are from academic journals, 10% came from reports, 2 conferences and news articles respectively as shown in Fig. 2's illustration of publication type.

According to the search criteria, all of the discovered publications were released between 2001 and 2023. The publications are shown in Fig. 3 by year. There has been an increasing interest in weather derivatives since developed (1997). The majority of publications, with a peak in 2011, were released between 2000 and 2023. This increased interest may be a sign of greater interest in this field and growing understanding of the value of hedging instruments in several industries, including construction, mining, retail, and electricity. The most frequently employed research methodologies—multiple techniques (49%) modelling and simulation (35%)

ISSN: 2583-6129
DOI: 10.55041/ISJEM02886

and statistical analysis (16%)—were applied consistently throughout the duration of the investigation. Additionally, the journals Energy Economics, Energies, Energy, Applied Mathematical Finance, and Journal of Risk Finance were the ones that published research on weather derivatives and the energy sector the most frequently.

**Fig 2: Publications by type**

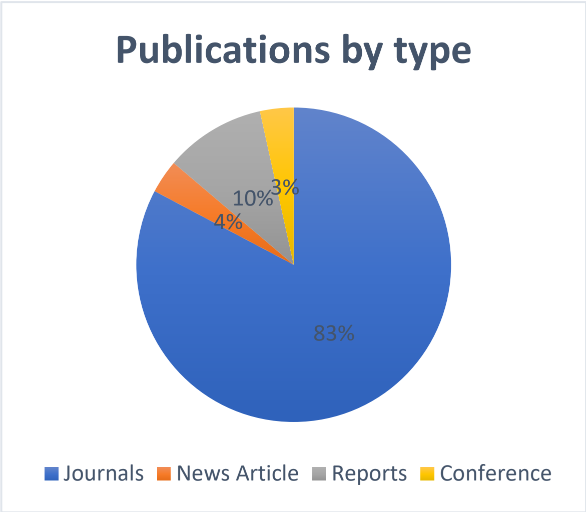
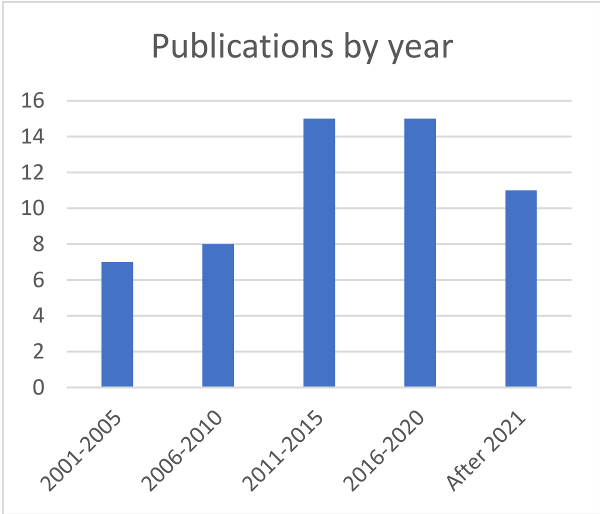



**Fig 3: Publications by year.**




In terms of geographical location of authors around 18% of them are from India, 9 % approximately from US and USA respectively as illustrated in Fig-4. Articles from the authors of Japan and Norway constitute around 6% of the total articles. Other country's contribution is comparatively less than these countries. However, most of the articles from India are conceptual in nature which demands for more in-depth study.

**Fig 4: Country wise no. of publications**

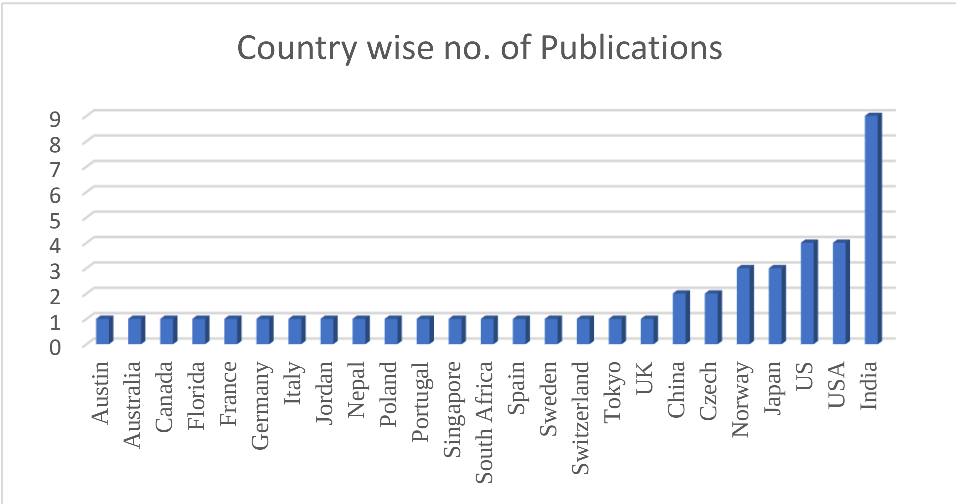
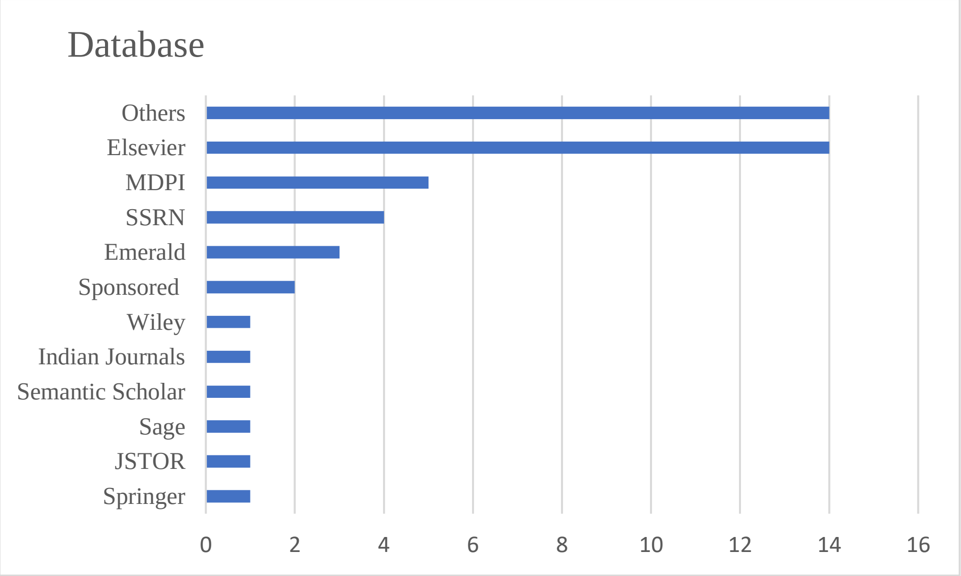



Fig 5 shows number of publications of the articles from different databases. Maximum of the journals are studies from Elsevier (Scopus) with 14 articles constituting 29% of total articles studied. Followed by it, articles from MDPI (10.4%), SSRN (8.33%), Emerald and Sponsored (4.10%) respectively are also studied. The rest 29% of the articles are from other databases such as Wiley, Indian Journals. Semantic Scholar. Sage, Springer, JSTOR.

**Fig 5: Publications from Database**




In the descriptive analysis, a deductive approach was employed to focus on the categorisation of the publications. The patterns of the descriptive analysis indicate a rising interest in weather derivatives.

## 4. Thematic Results: Understanding three key constructs

The systematic literature review was structured on three fundamental ideas that support the idea of weather derivatives. These include how weather derivatives have changed over time and how they are used in the power sector, as well as how climate change has an impact on the energy sector. The idea behind the operational model for weather derivatives and how it interacts with the energy sector served as the foundation for the synthesis. The writers researched each selected study in depth, drawing reliable conclusions on the constructs by analysing and interpreting them. The constructs will now be discussed individually.

### *4.1 Weather Impact on Power Sector*

The weather has always been unexpected, whether it's in terms of temperature, precipitation, frost, or snow. One of the economic areas deemed to be most sensitive to weather is the power sector (Ghiulnara & Viegas, 2010). Power system design and operations are faced with new and unanticipated issues due to change in climate.

The energy industry and climatic changes are interwoven, and using renewable energy in the energy sector can assist to lessen the effects of climate change. (Bhattacharjee, Das, & Nandi, 2023). A significant portion of the fluctuation in electrical generation, demand, and price is explained by unforeseen inflow, snowfall, and temperature circumstances (Johnsen, 2001). (Kezunovic, Dobson, & Dong, 2008) highlighted new technical difficulties that the electric power industry is currently facing, evaluated the patterns in the future global environment, and provided some opinions on the influence on power system blackouts and equipment failures. Although the weather may not be a major factor in influencing the retail price of power, it is one of the most significant factors impacting electricity demand (Ghiulnara & Viegas, 2010). In their analysis of the impact of numerous meteorological factors (including wind speed, temperature, relative humidity, and cloud cover) on Italy's monthly electricity demand, (Apadula, Bassini, Elli, & Scapin, 2012) they came to the conclusion that temperature is the factor that has the greatest impact on electricity demand. A similar kind of result was concluded by (Chikobvu & Sigauke, 2013) of South Africa. Furthermore, according to (AlDahmi, 2018) meteorological conditions such as high summertime temperatures and humidity as well as the population of the Al Ain area all contribute to high peak demand. According to a 2019 World Bank report, natural disasters and climate change were to blame for 37% of outages in Europe between 2010 and 2017 and 44% of power disruptions in the US between 2000 and 2017 (Handayani, 2020). According to a Spanish study, recent and current temperatures, especially hot degree days, have an impact on Spain's electrical load (Pardoa, Meneua,, & Valorb, 2002). The recent power disruptions in India brought on by the early arrival of summer should serve as a reminder to make the required adjustments to planning in the energy sector so that we are ready for the hard future that lies ahead (Singh, 2022). It was discovered by examining the factors impacting the load that the relationship between the variation in electricity demand and temperature had both positive and negative effects on the demand. (Rajbhandari, et al., 2021). Power generation companies are impacted at a higher rate than the power distributors as generation of power is directly dependent on weather, basically rainfall. While the revenue of hydroelectricity generation is highly exposed to monsoon rainfall fluctuation, the revenue of retail power distributors is only moderately exposed to daily surface temperature variations. As a result, the hydro-generator may suffer significant revenue loss due to insufficient monsoon rainfall (Basu & Chakraborty, 2019). As transmission and distribution facilities experience significant damage from weather-related power outages, they frequently have a severe impact and last for a sustained period of time, ranging from hours to days (Pantelia & Mancarellab, 2015). The possible effects of weather risk are frequently referred to as volumetric risks because they primarily affect volume and not (at least immediately) price (Prabakaran & Singh, 2017). When temperatures rise above 30ºC from demand at temperatures of 21–24 ºC, India's overall demand for power rises by 11% or more on average, with significant state-level variation (Harish, Singh, & Tongia, 2020). A study in Shanghai cited that a 1ºC increase in daily temperature reduces electricity use by 2.8% on days that are 7ºC or colder. A 1ºC rise in daily temperatures on warm days >25ºC results in a 14.5% rise in electricity use (Li, Pizer, & Wu, 2018). Similar kind of studies are conducted in Hong Kong and Singapore. A 1ºC rise in temperature is predicted to result in an increase in total annual electricity usage of Singapore between 3% to 4% in 2015 and between 4% to 5% are the similar projections for Hong Kong (Ang, Wang, & Ma, 2017). Study says that the smallest load occurs when the average daily temperature is between 15ºC and 18.34ºC, with temperature response curves for both average and peak load broadly resembling parabolas. In addition, peak load responds to temperature changes more quickly than normal load (Allen-Dumas, KC, & Cunliff, 2019). Increased sea level rise, more frequent and intense extreme weather events, higher temperatures, and other factors are all expected to have a variety of repercussions (ADB, 2012). Companies are severely affected from these extreme weather changes. The majority of the Polish energy sector enterprises under examination handled their relevant weather risk exposures, and the authors found that weather risk was commonly mentioned as one of the important or strategic concerns affecting their performance and cost-revenues dimension (Kosmala, 2020). In terms of the climatic variables along with companies, residential households are also affected by weather sensitivity. (Ang, Wang, & Ma, 2017) studied that the residential sector would have the most percentage growth in electricity use, followed by the commercial and industrial sectors. Making it more accessible for low-income households to utilise electricity for cooling purposes during the hottest times of the year could have a significant positive impact on health outcomes, productivity, and general well-being (Harish, Singh, & Tongia, 2020). The reaction of building energy usage to climate and the response of emissions to corresponding demand are highly regionalized (Meier & et al, 2017). The pattern of power consumption in Jordan is greatly influenced by climatic elements as well as demographic, technological, environmental, and national energy pricing issues (Momani, 2013). When hourly ramp-rates broaden by 50% and year-to-year variability climbs by 80%, future studies of the power sector must account for data collected over a larger period of time and examine how the weather influences its supply and demand (Staffell & Pfenninger, 2018).

### *4.2 Evolution of Weather Derivatives*

Recent research suggests weather derivatives as a versatile risk management strategy. A weather derivative is a contract between two parties that stipulates how payment will be exchanged between the parties, depending on certain meteorological conditions during the contract period. It is designed to provide indemnity against non-catastrophic weather events risk. Weather derivatives are usually structured as swaps, futures and call or put options based on different underlying weather indices (Alaton & Stillberger, 2022). Weather derivatives differ from standard derivatives in one important way. Weather derivatives, unlike other derivatives, aren't utilised to hedge the price of the underlying because the weather can't be priced. They are used rather as a proxy to hedge against other risks affected by adverse weather conditions. These allows companies, to manage or 'hedge' their weather-related risk exposures (Paul, 2013). As a result, weather derivatives can be seen as a useful tool for reducing the risk associated with unpredictable weather and preventing its adverse effects on corporate profitability. (Jones, 2007) and (Taušer & Čajka, 2014) inferred that weather derivatives allows industries with temperature-sensitive revenues to better manage the risk of unfavorable temperature changes. It provides the opportunity to hedge against suboptimal weather conditions at reasonable costs. There is a huge potential and expanding market for weather derivatives globally due to the increased impact of climatic changes on the economic development of the nation (Pandey & Kaur, 2013). The aim of weather derivatives is to smoothen earnings, to cover excess costs and to use it as an alternative to diversify portfolio investment. Weather derivatives can be traded in temperature, rainfall, snowfall, wind, cloud, etc. (Boyle, Haas, & Kern, 2021) developed an irradiance-based weather derivatives to hedge cloud risk for solar energy systems in which the results indicate that contracts are effective in cloudier climates with increasing utility for mines installing solar energy systems until the year 2030s.

The liberalisation of the US energy market in the mid-1990s and the extraordinarily warm El Nino winter of 1997–1998 are credited with giving rise to the weather derivatives market. With the liberalisation, monopolies started to give way to competitive market structures, and many energy and utility companies discovered that while they could use futures and options on energy itself to hedge away price risk, they lacked a similar tool to do the same for weather risk, which could significantly alter demand for their goods and services. So, in this context Weather Derivatives was introduced in the year 1997 by Aquila Energy as a weather option embedded in a power contract with an over-the-counter (OTC) transaction between Koch Industries Inc. and the Enron Corp., based on the temperature index for Milwaukee (Brockett, Wang, & Yang, 2005).

The following characteristics characterise a weather derivative contract: (1) a start and end date for the contract period; (2) a measurement station; (3) a weather variable, such as temperature, rainfall, snowfall, wind speed, and sunshine hours, measured at the meteorological station over the contract period; (4) a weather index, which aggregates the weather variable over the contract period; (5) A pay-off function, according to which a derivative contract is settled immediately after the conclusion of the contract period; and (6) For some types of weather derivative contracts, a premium paid by the buyer to the seller at the beginning of the contract (Jewson, Brix, & Ziehmann, 2005). At maturity, weather derivatives are monetarily settled based on how far the underlying weather index deviates from the target strike index. Strike level is often estimated as the 10-year historical average and reflects the expected value of the weather index. According to some writers, it is more accurate to incorporate weather observations spanning 20 to 40 years in order to account for more fluctuation (Dischel, 2002). However, recent weather data will be more helpful in predicting future weather by providing a more credible strike level. Since investors can balance their positions on the market before the contract matures, it is not essential to hold the contract until it matures (Taušer & Čajka, 2014)

Weather insurance is also an alternative to Weather derivatives but is used as a proxy for economic loss, which underwrites a weather risk that is often significantly connected with losses in agricultural production, and is

ISSN: 2583-6129
DOI: 10.55041/ISJEM02886

popular in lower-income nations (Taušer & Čajka, 2014) and (Choksi, 2012) few well-known researchers in India have suggested for weather insurance over the country's conventional insurance programme. Although weather index insurance could have various advantages in this situation (such as giving vulnerable households a safety net and providing price signals on the weather risk), climate change impacts raise the cost of insurance owing to increasing weather risks (Collier, Skeesa, & Barnettb, 2009).

Weather derivatives are standardised contracts, those traded on OTC market both for insurance and re-insurance purposes. The only regulated platform or exchange that currently allows trading in weather derivatives is the Chicago Mercantile Exchange (CME). The CME offers Heating Degree Day (HDD) and Cooling Degree Day (CDD) futures contracts and options on futures for monthly and seasonal temperature related events. HDD futures and options are traded on the Autumn and winter months of October through April, while CDD futures and options are traded on the spring and summer months of April through October in CME. Also, the London International Financial Futures Exchange (LIFFE) first offered temperature weather options in London, Berlin, and Paris in 2001. However, due to a lack of demand and significant structural issues, the LIFFE discontinued weather derivative trading in 2004 (Tindall, 2006). Considering India, if the limitations are worked upon and subsequently removed, weather derivative should find a good market in India (Datta, 2018)**.**

### *4.3 Effectiveness of Weather Derivatives as Risk Mitigating Tool in Power Sector*

In addition to using other risk management tools, the application for weather derivatives objective is to lessen the costs' and/or revenues' erratic fluctuations by the unpredictable nature of non-catastrophic weather. Although it is considered as an alternative weather risk tool management, it will be considered effective if it decreases the excess costs, stabilize earnings, decreases volatility of realized profits thus reducing the uncertainty of expected future cash flows. Lesser the variability of profits higher will be the company's credit rating which will enable them to burrow capital at lesser rates.

The use and efficacy of weather derivatives have been investigated and demonstrated in power sector. (Masala, Micocci, & Rizk, 2022) studied the effectiveness of weather derivatives and introduced the industrial portfolio of a wind farm of a hypothetical company, as well as its financial market valuation. They presented and explained a static risk management approach derived from hedging against volumetric risk due to drops in wind intensity. The application of Engle's model was assessed to formally characterize the relationship between electricity price and wind intensity. They found that the changes in price due to wind speed were negligible. They also showed the implications of a hypothetical volumetric risk hedging approach with collar options and inferred that the "worst value" increases significantly while the earnings-at-risk (EaR) drops in the hedged portfolio. In another study the authors concluded that weather derivatives had considerable advantages for weather-sensitive firms. The trading has grown since the deregulation process began. Electricity is no longer used only for power, but increasingly in the form of derivatives for hedging or speculation on price rises or falls (Jilek, 2002). (Lai, Qui, Tao, & Liu, 2022) studied the effectiveness of weather derivatives for electricity retailers in China. The application of strangle was accessed and temperature (HDD & CDD) was defined as the underlying weather index. Simulation results show that the overall profits of the retailer employing the proposed hedging model are higher than the traditional model, and the conventional model's overall profit variation is around 26% larger than that of the proposed model. (Matsumoto & Yamadab, 2021) studied the effectiveness of weather derivatives in electricity business in Japan based on the square of temperature prediction error. The results conclude that the profit/loss fluctuation risks of both parties may be mitigated if these standardized derivatives are exchange liquidly in a weather derivative market and traded between (renewable) power producing businesses and merchants with the opposite profit structure. (Stulec, Bakovic, & Hruska, 2012) studied the effectiveness of weather derivatives as weather risk management in energy sector in Austria by outlining possible strategies to mitigate weather risk. The results presented was both in case of energy consumption and energy production which shows that weather derivatives have high potential for energy sector, especially considering exploitation of renewable sources. Weather derivatives could be used based on demand for each field in Portugal's fast growing renewable energy sector (Ghiulnara & Viegas, 2010). (Deng & Oren, 2006) studied the effectiveness of electricity derivatives in California. The author highlighted the role of these financial instruments in managing weather risk and constructing hedging plans for power marketers, load serving organizations, and generators in various risk management applications. The article concluded that energy derivatives can provide price certainty, implement interruptible service contracts, hedge volumetric risk, and synthesize generating and transmission capacity. Also, they emphasized the importance of standardization of weather derivatives which will decrease transaction costs and provide liquidity. (Basu & Chakraborty, 2021) studied the effectiveness of weather derivatives in weather risk management in Indian Power sector. The author applied the autoregressive component in the presence of GARCH. The study finds that the volumetric risk brought on by temperature fluctuations can be successfully hedged using weather derivatives even under the semi-administrative pricing structure now in place in the Indian power sector. (González & Yun, 2013) studied the effectiveness of weather derivatives in electric utilities in US. The results show that risk management through weather derivatives has a significant impact on decisions regarding valuation, investments, and financing as well as the ability of financial innovation to significantly impact firm outcomes. (Janda & Vylezik, 2011) studied the effectiveness of weather risk management through weather derivatives. The results show that the most popular tools used by energy businesses are weather derivatives (HDD put options), which are used particularly as a protection against unusually high winter temperatures. If these standardized derivatives are traded liquidly in a weather derivative market and traded between (renewable) power generation companies and retailers with the opposite profit structure, the profit/loss fluctuation risks of both parties may be reduced at the same time. By using ANOVA decomposition, they captured the structure of the hedge model and showed that multiple different payoff functions, such as minimum and maximum temperatures, which can be estimated simultaneously and effectively. (Matsumoto & Yamadab, 2021). (Prabakaran & Singh, 2017) derived the Black–Scholes option pricing model to determine whether the consumer/corporate should make a decision before making the agreement on whether to enter the option market by taking an illustration and were successful in contributing to the electricity market. The effectiveness of the instrument vary from country to country, time to time as well as model to model. According to (Bhattacharya, Gupta, Kar, & Owusu, 2020) there is significant benefit of natural hedge in certain months of the year, while in others, explicit hedges can effectively modify risk exposure. The solar power producer is at a higher profitability variation risk during the fringe summer and winter months and enabled them to formulate robust cross hedging strategies for other risks of renewable power producers. Regarding techniques, finite difference techniques can be used to value weather derivatives (Pirrong & Jermakyan, 2008). With respect to pricing, based on 1 year of observed prices for wind power futures with different delivery periods, authors study the market price of risk and found a negative risk premium whose magnitude decreases as the length of the delivery period increases (Bentha & Pircalabu, 2018). As analysed by (Matsumoto & Yamada, 2021) non-parametrically priced derivatives can maximize the hedge effect when a hedger bears a "price risk" with high nonlinearity to temperature. In contrast, standard derivatives are more useful for utilities with only "demand risk" in having a comparable hedge effect and in being liquidly traded. Another study by (Aïd, Campi, & Langrené§, 2013) conducted an analysis of the electricity price risk premium showing the contribution of demand and capacity to the futures prices. They concluded that when far from delivery, electricity futures behave like a basket of futures on fuels. (Matsumoto & Yamada, 2023) in another study concluded that diversification of hedging instruments increases transaction flexibility and helps wind power generators find more efficient portfolios, which can be generalized to risk management practices in other businesses. In another study a dynamic hedging strategy was proposed by using temperature futures for energy futures. They reviewed that the estimation of initial hedge ratios showed that

International Scientific Journal of Engineering and Management (ISJEM) ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025 DOI: 10.55041/ISJEM02886
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

the hedgers need more temperature futures when the delivery time of their energy futures in position getting longer and current spot price getting more expensive (Cui & Anatoliy, 2015). (Matsumoto & Yamada, 2019) proposed a method using a tensor-product spline function that simultaneously incorporates the smoothing conditions of both the direction of intraday time trend and seasonal trend, and consequently verify its effectiveness. They concluded that hedge effect was improved by up to 62% by using the solar radiation derivative and temperature derivative together. (Kratochvíl & Starý, 2013) described the models used for predicting electricity prices on energy exchanges such as mean-reversion, jump-diffusion and regime-switching models. They also predicted new spot price values, and compared these data with actual measured values. From both the MAE and the RMSE, the best results were achieved for the jump-diffusion model and the calibration of the 2009 data and the filtered data. Again, they calculated the future price by smoothing the spot price using a Monte Carlo simulation and the moving average method. They proved that among the smoothing methods for spot prices, the moving average method achieved the best results, and among the spot price prediction models (one of which was used to calculate future prices) the mean-reversion model achieved the best results. Also, the volatility of these futures will decrease when approaching maturity, an effect which is explained by the memory in higher-order autoregressive models (Benth & Benth, 2009). (Ellithorpe & Putnam, 2000) reviewed and reflected that a power company can successfully hedge against the severe economic loss that would be incurred in the event that power prices are unlikely to spike (mild summer).

According to the literature review there is no widely recognized indicator of the efficiency of weather derivatives. While evaluating effectiveness, the majority of researchers analyze variance and semi-variance and Monte Carlo simulations, whereas the methods like mean-variance criterion, value-at-risk are employed less frequently. Effectiveness of weather derivatives varies between different players in energy sector, geographical locations and time periods. A unique weather-sensitivity study and a tailored design of weather derivatives are required due to the specifics of the weather risk.

## 5. Thematic Synthesis

**Table-2: Summary of Review of Related Literatures**

| **Objectives** | **Discussion/ Findings** | **Suggestion** |
|---|---|---|
| Weather impact on power sector | Power generation, transmission and distribution companies are severely impacted by the power shortage which lasts for several hours to days. | Further study on the electric grid needs to be considered. Data needs to be analyzed over many years and examine the weather impacts on power demand and supply. |
| Evolution of weather derivatives | Weather derivatives is used as a proxy to hedge against non-catastrophic risks affected by adverse weather conditions. Literatures conclude that weather derivatives are one of the innovative and alternative weather risk hedging instruments. Weather insurance is also an alternative but that is limited to catastrophic losses only. | As power sector is one of the highly sensitive weather prone sector, weather derivatives could be used in this sector to mitigate risk of adverse weather conditions (non-catastrophic losses). It could be helpful in stabilising the earnings, managing profit volatility and controlling excess costs. |
| Effectiveness of weather derivatives as a risk mitigating tool in power sector | Weather derivatives are found to be effective in hedging non-catastrophic weather risk of different players in the power sector. It can be effectively used as an alternative weather risk mitigating tool. However, there is a lack of adequate infrastructure and historical time | For the successful creation of weather derivatives, the study suggests that the creation of new markets, legal frameworks, and socio- economic systems are all necessary. Also, power markets are not fully integrated |

| | | |
|---|---|---|
| | series meteorological information is a significant barrier. | with the broader financial markets. Supply of historical time series climate data could be made available on the government climate-based websites to make the information easily accessible by researchers for further study. |

## 6. Conclusion

Various studies reveal that economy is affected worldwide directly or indirectly by adverse weather conditions. Primarily, agriculture sector is hugely affected by the sensitive weather indicators but along with this sector many other sectors are also impacted by the vulnerability of the weather conditions. Among them power sector is one which shows high weather sensitivity. So, as to mitigate the weather risk, weather insurance is found to be one of the effective financial instruments to cover only catastrophic risk. However, for dealing with non-catastrophic weather risk like seasonal variations in demand and supply, revenue fluctuations, risk volatility, etc., weather insurance has proved to be ineffective. Contrarily, weather derivatives offer an adaptable and flexible non-catastrophic weather risk management approach with entirely objective pay-offs, decreasing the problems with moral hazard and adverse weather problems. Companies had few options for managing non-catastrophic weather risk until the introduction of weather derivatives. But due to increased rate of volatility in the weather conditions, companies are required to adopt feasible and sustainable strategies for managing weather risk. Power sector is highly weather sensitive because the generation, transmission and distribution of power are affected by multiple meteorological factors such as temperature, rainfall, wind, etc. So, this arises the need for a weather hedging instrument which covers non catastrophic weather risk known as "weather derivatives".

The use and effectiveness of weather derivatives have been investigated and validated in power sector. The most commonly used underlying is temperature and rainfall index using various methods like ANOVA, Monte Carlo simulations, etc. However, there is no common method used by authors world-wide. The effectiveness of weather derivatives can be judged with the results of lower volatility of profits, stable earnings and decrease in excess costs. The existing literatures show that the weather derivatives are effective in hedging adverse non catastrophic weather events that varies from region to region and between different time periods. But due to lack of adequate infrastructure, unavailability of freely accessible data, legal framework and socio-economic system weather derivatives have not been introduced in Inda yet.

The outcome of the paper is demonstrated in the description of weather derivatives and its effectiveness in power sector. After reviewing the research, it is outlined that the weather derivatives is an effective tool in mitigating risk of non-catastrophic weather risk in power sector. Further study may be conducted to compare the efficiency of various models of weather derivatives and its pricing.

**References**

ADB. (2012). *Climate Risk and Adaptation in the Electric Power Sector.* Philippines: Asian Development Bank.

Aïd, R., Campi, L., & Langrené§, N. (2013). A structural risk-neutral model for pricing and hedging power derivatives. *Mathematical Finance*. doi: 10.1111/j.1467-9965.2011.00507.x

Alaton, P., & Stillberger, D. (2022). On modelling and pricing weather derivatives. *Applied Mathematical Finance, 9*(1), 1-20.

ISSN: 2583-6129
DOI: 10.55041/ISJEM02886

AlDahmi, M. (2018). A Review of Factors Affecting Electricity Peak Demand in Al Ain Area. *Asia-Pacific Power and Energy Engineering Conference.*

Allen-Dumas, M. R., KC, B., & Cunliff, C. I. (2019). *Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods.* Oak Ridge NAtional Laboratory.

Alzarrad, A., Moynihan, G., & Vereen, S. C. (2017). Weather Derivatives as a Risk Management Tool for Construction Projects. *6th CSCE/CRC International Construction Specialty Conference.* Vancouver, Canada.

Ang, B. W., Wang, H., & Ma, X. (2017). Climatic influence on electricity consumption: The case of Singapore and Hong kong. *Energy, 127*(C), 534-543.

Apadula, F., Bassini, A., Elli, A., & Scapin, S. (2012). Relationships between meteorological variables and monthly electricity demand. *Applied Energy, 98*, 346-356.

Basu, M., & Chakraborty, T. (2019). Weather risk assessment of Indian Power Sector: A Condiitonal Value-at-risk approach. *Energy and Environment*, 641-661.

Basu, M., & Chakraborty, T. (2021). Risk Management Through Weather Derivative in Indian Power Sector: Perspective of an Indian Power Firm. *The IUP Journal of Applied Economics, 20*(3), 7-27.

Benth, F. E., & Benth, J. Š. (2009). Dynamic pricing of wind futures. *Energy Economics, 31*, 16-24.

Bentha, F. E., & Pircalabu, A. (2018). A non-Gaussian Ornstein–Uhlenbeck model for pricing wind power futures. *Applied Mathematical Finance, 25*(1), 36-65.

Bhattacharjee, S., Das, I., & Nandi, C. (2023). A data-centric analysis of climate change in India: A reflection on electricity sector. *Technological Forecasting & Social Change, 190*.

Bhattacharya, S., Gupta, A., Kar, K., & Owusu, A. (2020). Risk management of renewable power producers from co-dependencies in cash flows. *European Journal of Operational Research, 283*, 1081-1093.

Boyle, C. F., Haas, J., & Kern, J. D. (2021). Development of an irradiance-based weather derivative to hedge cloud risk for solar energy systems. *Renewable Energy, 164*, 1230-1243.

Brockett, P. L., Wang, M., & Yang, C. (2005). Weather Derivatives and Weather Risk Management. *Risk Management and Insurance Review, 8*(1).

CDP India Disclosure Report. (2021). *Disclosure: Imperative for a Sustainable India.* Carbon Disclosure Project, India. Retrieved from https://cdn.cdp.net/cdp-production/cms/reports/documents/000/006/164/original/CDP_AnnualDisclosureReport2021_V7.pdf?1663682392

Chikobvu, D., & Sigauke, C. (2013). Modelling influence of temperature on daily peak electricity demand in South Africa. *Journal of Energy in Southern Africa, 24*(4).

Choksi, A. (2012). Emergence of Weather Derivatives- Feasibility in Indian Context. *ZENITH International Journal of Business Economics & MAnagameent Research, 2*(5), 139-152.

Collier, B., Skeesa, J., & Barnettb, B. (2009). Weather Index Insurance and Climate Change: Opportunities and Challenges in Lower Income Countries. *The Geneva Papers on Risk and Insurance. Issues and Practice*, 401-424.

Connors, R. B. (2002). Weather derivatives allow construction to hedge weather risk. *Cost Engineering*, *45*(3), 21-24.

Cui, K., & Anatoliy, S. (2015). Applications of Weather Derivatives in Energy Market. *Journal of Energy Markets*.

Datta, B. S. (2018). Feasibility and Deterrents of Weather Derivatives- A Review in the Indian Context. *International journal of basic and applied research*, *8*(3), 129-139.

Deng, S. J., & Oren, S. S. (2006). Electricity derivatives and risk management. *Energy*, 940-953.

Deyner, D., & Tranfield, D. (2009). Producing a systematic review. In A. Buchanan, & A. Bryman, *The SAGE Handbook of Organizational Research Methods* (pp. 671-689). London: Sage Publications Ltd.

Dischel, R. S. (2002). Climate risk and the weather market: financial risk management with weather hedges. *Risk Waters Group*.

Dutton, J. A. (2002). Oppurtunities and Priorities in a New Era for Weather and Climate Services. *Bulletin of the American Meteorological Society*, *83*(9), 1303-1311.

Ellithorpe, D., & Putnam, S. (2000). Weather Derivatives and Their Implications for Power Markets. *The Journal of Risk Finance*, *1*(2), 19-28. doi:Ellithorpe, D., & Putnam, S. (2000). Weather Derivatives and Their Implications for Power Markets. The Journal of Risk Finance, 1(2), 19–28. doi:10.1108/eb043442

Ghiulnara, A., & Viegas, C. (2010). Introduction of weather-derivative concepts: perspectives for Portugal. *The Journal of Risk Finance*, 9-19.

González, F. P., & Yun, H. (2013). Risk Management and Firm Value: Evidence from Weather Derivatives. *The Journal of Finance*, *68*(5), 2143-2176.

Handayani, K. (2020). *How climate-related weather conditions disruptpower plants and affect people.* The Conversation.

Harish, S., Singh, N., & Tongia, R. (2020). Impact of temperature on electricity demand: Evidence from Delhi and Indian states. *Energy Policy*.

Janda, K., & Vylezik, T. (2011). Financial Management of Weather Risk with Energy Derivatives. *Munich Personal RePEc Archive*.

Jewson, S., Brix, A., & Ziehmann, C. (2005). Weather Derivative Valuation: The Meteorological, Statistical, Financial and Mathematical Foundations. *Cambridge University Press*.

Jilek, J. (2002). Finanční a komoditní deriváty. *Praha*.

Johnsen, T. A. (2001). Demand, generation and price in the Norwegian market for electric power. *Energy Economics*, 227-249.

Jones, T. L. (2007). Applications Of Weather Derivatives. *International Business & Economics Research Journal, 6*(6).

Kezunovic, M., Dobson, I., & Dong, Y. (2008). Impact of Extreme Weather on Power System Blackouts and Forced Outages : New Challenges. *Engineering, Environmental Science*.

Kosmala, M. W. (2020). Weather Risk Management in Energy Sector: The Polish Case. *Energies*.

Kratochvíl, Š., & Starý, O. (2013). Predicting the Prices of Electricity Derivatives on the Energy Exchange. *Acta Oeconomica Pragensia, Prague University of Economics and Business, 21*(6). doi:DOI: 10.18267/j.aop.421

Lai, S., Qui, J., Tao, Y., & Liu, Y. (2022). Risk hedging strategies for electricity retailers using insurance and strangle weather derivatives. *International Journal of Electrical Power and Energy Systems*.

Larsen, P. H. (2006). An Evaluation of the Sensitivity of U.S. Economic Sectors to Weather.

Li, Y., Pizer, W. A., & Wu, L. (2018). Climate change and residential electricity consumption in the Yangtze River Delta, China. *PNAS*.

Masala, G., Micocci, M., & Rizk, A. (2022). Hedging Wind Power Risk Exposure through Weather Derivatives. *Energies*.

Matsumoto, T., & Yamada, Y. (2019). Cross Hedging Using Prediction Error Weather Derivatives for Loss of Solar Output Prediction Errors in Electricity Market. *Asia-Pacific Financial Markets, 26*, 211-227.

Matsumoto, T., & Yamada, Y. (2021). Customized yet Standardized Temperature Derivatives: A Non-Parametric Approach with Suitable Basis Selection for Ensuring Robustness. *Energies, 14*.

Matsumoto, T., & Yamada, Y. (2023). Improving the Efficiency of Hedge Trading Using Higher-Order Standardized Weather Derivatives for Wind Power. *Energies, 16*.

Matsumoto, T., & Yamadab, Y. (2021). Simultaneous hedging strategy for price and volume risks in electricity businesses using energy and weather derivatives. *Energy Economics*.

Meier, P., & et al. (2017). Impact of warmer weather on electricity sector emissions due to building energy use. *Environment Research Letters*.

Mohanty, A., & Mohanty, B. (2014). Power Sector Efficiency - A Review. *XIMB Journal of Management, 11*(1), 83-111.

Momani, M. A. (2013). Factors Affecting Electricity Demand in Jordan. *Energy and Power Engineering, 5*, 50-58.

Pandey, V. K., & Kaur, H. (2013). Weather derivative: A New Market Innovation. *Asia Pacific Journal of Management & Entrepreneurship Research, 2*(3), 160-168.

Pantelia, M., & Mancarellab, P. (2015). Influence of Extreme Weather and Climate Change on the Resilience of Power Systems: Impact and Possible Mitigation Strategies. *Electric Power Systems Research, 127*. doi:10.1016/j.epsr.2015.06.012

ISSN: 2583-6129
Volume: 04 Issue: 04 | April – 2025
DOI: 10.55041/ISJEM02886
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata

Pardoa, A., Meneua,, V., & Valorb, E. (2002). Temperature and seasonality influences on Spanish electricity load. *Energy Economics*, 55-70.

Paul, J. (2013). A Study on the Feasibility of Weather Derivatives in India. *Indian Journal of Research, 2*(1), 14-15.

Pirrong, C., & Jermakyan, M. (2008). The price of power: The valuation of power & weather derivatives. *Journal of Banking & Finance, 32*, 2520-2529.

Pirrong, C., & Jermakyan, M. (2008). The price of power: The valuation of power and weather derivatives. *Journal of Banking and Finance, 32*, 2520-2529.

Prabakaran, S., & Singh, J. P. (2017). Modeling and Pricing of Weather Derivative Market. *Global Journal of Pure and Applied Mathematics., 13*(12), 8103-8126.

Rai, P. K., & Rai, P. K. (2013,). Environmental and socio-economic impacts of global climate change: An overview on mitigation approaches. *Environmental Skeptics and Critics, 2*(4), 126-148.

Rajbhandari, Y., Marahatta, A., Ghimire, B., Shrestha, A., Gachhadar, A., Thapa, A., . . . Korba, P. (2021). Impact Study of Temperature on the Time Series Electricity Demand of Urban Nepal for Short-Term Load Forecasting. *Applied System Innovation, 4*(43).

Singh, D. (2022). *India's power sector must brace for trouble asclimate worsens. Govt can't sit back.* The Print.

Staffell, I., & Pfenninger, S. (2018). The increasing impact of weather on electricity supply and demand. *Energy*, 65-78.

Stulec, I., Bakovic, T., & Hruska, D. (2012). Weather Risk Management in Energy Sector. *23rd International DAAAM Symposium* (pp. 0089-0094). Austria, EU: DAAAM International.

Taušer, J., & Čajka, R. (2014). Weather derivatives and hedging the weather risks. *Agricultural Economics, Czech, 60*(7), 309-313.

Tindall, J. (2006). Weather Derivatives: Pricing and Risk Management Applications. *Institute of Actuaries of Australia*. Retrieved from https://actuaries.asn.au/Library/fsf06_paper_tindall_weather%20derivatives.pdf

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management, 14*, 207-222.