Using Customized Weather Derivatives to Hedge Earnings Volatility in Energy Markets[1]

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ABSTRACT

Weather and climate risks have significant impacts on the operating and financial decisions and results of many businesses, especially energy producers, distributors and retailers. To the extent that normal weather volatility and long-term climate trend (notably increasing occurrence of extreme weather) affect energy supply and demand, hedging strategies and instruments that can be employed to transfer these exposures to willing risk takers are very valuable.

This paper focuses on the strategies and instruments that are used to transfer specific weather and climate exposures inherent in both renewable energy sources (wind, solar, hydro) and traditional energy sources. We will explore today's weather market and the use of customized weather derivatives for directly transferring financial exposures due to weather and climate. The advantages of these types of instruments over pure commodity instruments will also be examined using examples of innovative transactions that have been executed globally.

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INTRODUCTION

Background

Weather and climate risks are important to the financial performance of many businesses across geographies and industries (see Table 1). However, they have traditionally been perceived as unmanageable. As a result, a number of businesses believe they have no choice but to retain the financial exposures arising from weather risk. Some of the more sophisticated companies make use of traditional financial instruments (notably commodity price futures and options) to indirectly minimize exposure to weather risk but such instruments are ineffective at managing volume risk.

The existence of exchange traded vanilla weather derivatives is known to many but several factors have prevented their effectiveness and development. The most limiting of these factors has been the bluntness of these instruments in replicating financial exposure due to index type, location, tenor and size. HDD and CDD are the most common weather indices traded on the Chicago Mercantile Exchange (CME) but with little liquidity. Other instruments that settle on average temperature, cumulative rainfall and snowfall are also available for some cities but with even less liquidity (or none for some locations).

To get around these shortcomings, the weather hedging/insurance industry has mostly developed via the Over-the-Counter (OTC) market where risk takers directly, or via intermediaries, offer hedging capacity to end users allowing the direct transfer of weather exposures through customized structures. Without the constraints of standardization of indices, location and tenor, hedgers and risk takers are able to customize weather contracts to fit the exposure of the end user, thereby reducing basis risk and increasing hedge effectiveness.

In the energy industry both the supply and demand sides are heavily influenced by seasonal deviations from normal weather and occurrence of extreme weather events. As illustrated in Figure 1, energy, fossil fuel and the environment are interrelated and are also dependent on the weather. Hence, financial risks arising from their supply and demand can be hedged with weather elements (i.e. precipitation, wind speed and solar irradiance). For example, due to baseload capacity shortfall arising from lower than expected seasonal weather (e.g. precipitation), a utility generator may have to run more expensive and/or polluting (e.g. coal) thermal power plants.

On the consumption side, demand for space cooling in the summer and space heating in the winter is known to vary with temperature. This is true on a seasonal average basis and also for days where temperature extremes are recorded (see Figures 2). For example, extreme cold snaps are typically accompanied by spikes in natural gas prices. Similarly, heat waves are known to strain electricity supply systems as demand for space cooling increases rapidly, leading to jumps in electricity price. Under these scenarios, a retail energy utility with forward supply contracts will be exposed to high cost of buying power or natural gas to meet unanticipated demand.

Table 1: Businesses and Weather Risk

Industry	Weather Variable	Weather Exposure
Energy	Precipitation, Temperature, Wind, Solar irradiance	Reduced or excessive demand Reduced or excessive supply
Agriculture	Precipitation, Temperature	Crop yield, handling, storage, pests
On Shore Construction	Wind, Temperature	Budget overruns, Schedule disruption
Sports & Entertainment	Precipitation	Cancellations, Schedule disruption
Retailing	Precipitation, Temperature	Reduced product demand
Transportation	Precipitation, Temperature	Budget overruns, delays
Travel	Precipitation, Temperature	Cancellations, Schedule disruption
Governments	Precipitation, Temperature	Budget overruns
Off-shore Construction	Wave, Wind	Budget overruns, Schedule disruption

Considering these examples and many others (e.g. see Table 2), such as the financing risk of renewable energy projects and the financial exposure arising from inability to access mining sites due to bad weather[4], the need to find innovative hedging solutions cannot be over stated.

Objectives

The objectives of this paper are to examine the strategies and instruments that are used to transfer weather risk exposures inherent in energy sources, including both traditional and renewable energy sources. The advantages of these types of instruments over vanilla commodity products are also examined. We make use of case studies to demonstrate the broad use of customized weather hedges, their effectiveness and advantages.

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[4] For instance, excessive precipitation resulting in flooding affects coal mining operations causing financial losses for miners or unanticipated jump in coal prices. Similarly, warmer than expected temperature in the winter can impact access to remote mining operations, via ice roads, in some northern hemisphere locations (e.g. northern Canada).

Figure 1: Weather and Energy Risk

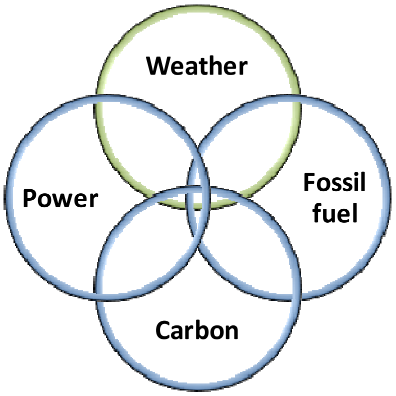
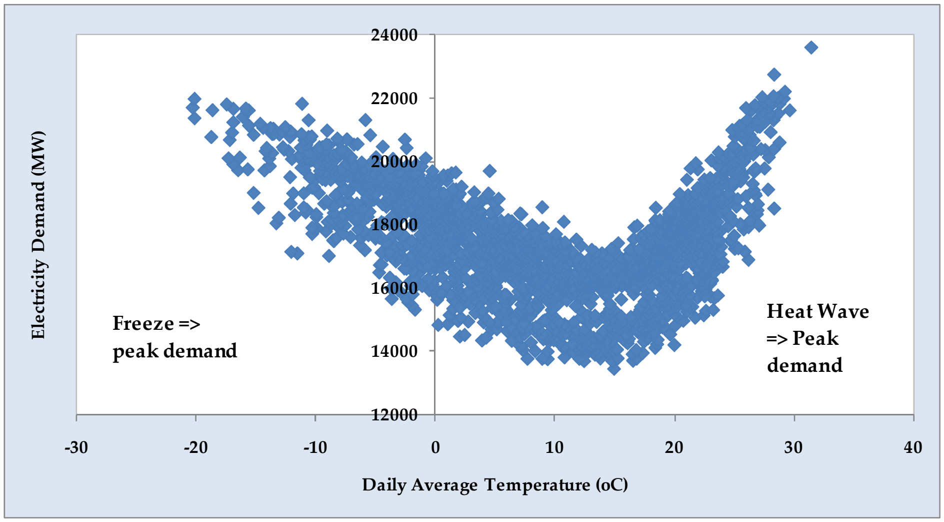


Table 2: Energy and Weather Dependence

Energy Source/demand	Weather Risk Exposure
Hydroelectric Energy	Low precipitation (rain, snow, river flow)
Wind Energy	Low wind speed implies below normal output; Long periods of high wind speeds during off-peak demand may cause problems for baseload generators
Solar Energy	Low solar irradiance implies below normal output
Thermal Energy	Mild temperature results in less than expected dispatch of marginal generators
Electricity Demand	Extreme temperature (heat wave/freeze) creates excess demand
Off-shore wind	Bad weather conditions cause delays and budget overruns during construction
Natural gas	Warmer than normal winters results in less than expected heating demand

Figure 2: Dependence of Power Demand on Daily Average Temperature in Ontario, Canada



HEDGING STRATEGIES

The right hedging strategy for a business depends on its risk exposure and risk transfer goals. A hedger's risk exposure is obviously a function of its core business and its associated risk factors. Therefore, the first step in determining the appropriateness of weather derivatives for a business is to assess the relationship of its cash flows to different weather elements. Once meaningful dependencies are established, the hedger then has to decide on how much risk it wants to transfer versus retain.

Hedgers that are new to weather derivatives or are cost sensitive may prefer to swap exposures with a risk taker, trading away potential revenue upside in exchange for protection under adverse financial outcomes. This type of protection can be achieved through a swap contract or a premium-neutral collar structure. For some other hedgers, paying an upfront premium to purchase options may be more appealing. Others are even able to lock in protection over a multi-year risk horizon.

Irrespective of the risk transfer goal(s) of the hedger, the opportunity to customize a hedge improves hedge effectiveness and reduces cost by removing the need to over buy protection. Using bespoke solutions, the hedger is able to transfer risk based on a customized underlying index that isolates coverage required, in terms of price and volume risk exposures.

Hedging Price Risk and Volume Risk

The payoff of a weather derivative can be defined in one of two ways:

1. Convert weather index(es) to volume exposure
   i.e. for volume V and weather index I,
   $$V = f(I) \tag{1}$$
   where f is a functional relationship between weather index and volume index

2. Specify a volume index (V), if a critical weather condition exists
   e.g. if $I >$ a threshold, $V =$ y where y is a constant or variable volume index.

For instance, using the first approach, one can define volume exposure from a weather index or combination of indexes using regression analysis. The payoff of a weather derivative could then be defined in terms of a volume structure multiplied by a notional amount (e.g. \$/°C) i.e.

$$Payoff = max(V - VS, 0) \times N \tag{2}$$

where VS is volume strike and N is notional.

For a pure weather derivative, the notional N is either an amount per unit of deviation from the volume index or an amount per critical weather event.

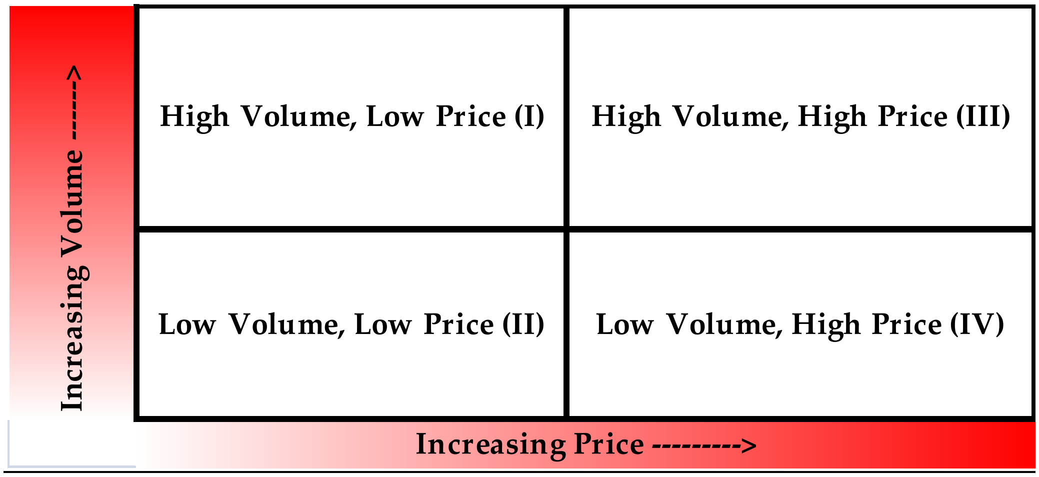
For situations where there is a significant price risk in addition to volume risk (e.g. if the hedger is a buyer or seller of a volatile commodity), there may be need to directly incorporate commodity price index into a weather derivative structure to create a weather-contingent commodity derivative such as quantos[5]. In this case, the notional N in equation (2) could itself be an option. For instance, if payoff is contingent on a commodity price index C relative to a cap price strike CS, equation (2) becomes:

$$Payoff = max(V - VS, 0) \times max(C - CS, 0) \tag{3}$$

A weather-contingent commodity derivative provides cost efficiency to a hedger by allowing the hedger to focus on the financial risk arising from the intersection of its price and volume risks exposures (as depicted in Figure 3). The figure simplifies risk exposure by dividing the intersection of price and volume risks into the four quadrants of a rectangle. In the first quadrant, financial risk exposure arises from the joint occurrence of low commodity price and higher than normal volume (or demand). However, in the third quadrant, financial risk arises from higher than normal demand and commodity price occurring simultaneously.

For practical purposes, the financial exposure of a hedger could potentially cover one or more of the quadrants but not all. By focusing on the specific quadrant(s) of interest, the coverage required by a hedger could be isolated and hedged with a bespoke weather-contingent commodity derivative.

Figure 3: Intersection of Price and Volume Risks



High Volume, Low Price (I)	**High Volume, High Price (III)**
Low Volume, Low Price (II)	**Low Volume, High Price (IV)**

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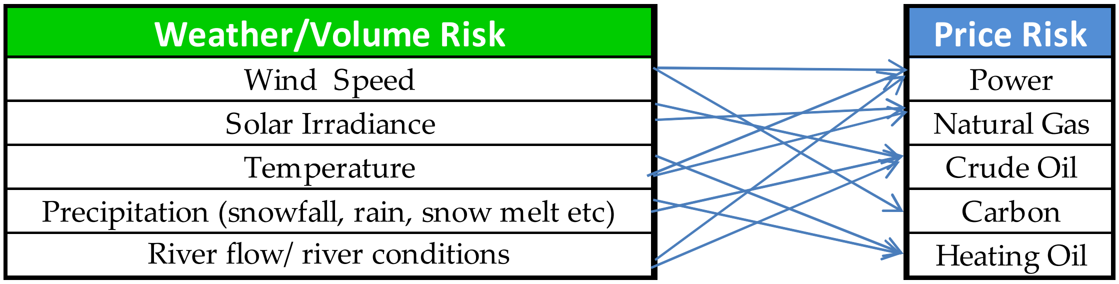
[5] quantity options

In theory, this type of bespoke coverage could be structured across the spectrum of energy commodities and weather indices as illustrated in Figure 4. For example, a natural gas retail utility may have to buy gas from the spot market when actual demand exceeds projected demand due to persistent cold temperatures. However, if spot gas prices remains at normal levels (or below) during that period, the resulting financial exposure may be manageable. Therefore, instead of hedging price spike risk by buying natural gas calls (which would not respond in this scenario) , the hedger could enter into a weather-contingent natural gas contract to receive payments in a high volume-high price scenario (i.e. quadrant III).

<u>**Figure 4: Spectrum of Energy Commodities Dependencies on Weather**</u>



Cost Advantage of Weather-Contingent Derivatives

The pricing of a weather-contingent commodity derivative is a function of the dependence between the underlying weather and commodity indexes. In a simple situation, this dependence could be captured with a linear correlation such that pricing then becomes a function of correlation, everything else held constant. Mathematically, if we assume that the weather index I and the commodity index C are stochastic variables driven by two Wiener processes (W)[6], the time(t)-dependent joint evolution of the indexes (i.e. risks) is related to correlation ρ as follows:

$$dW_t{}^I dW_t{}^C = \rho dt \qquad (3)$$

On this basis, we can identify a lower bound and an upper bound for the price of a weather-contingent commodity derivative as follows:

1. Upper bound: price of the commodity derivative
2. Lower bound: probability of weather index trigger multiplied by the price of commodity derivative

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[6] This is also true for the more realistic stochastic processes

The upper bound price applies when ρ = 1, in which case there is a perfect dependence between weather index and commodity price index. When ρ=0, the lower bound applies. In any case, as long as there is no perfect dependence between the weather index and the commodity index of interest, the cost of hedging with a weather-contingent solution should be lower than a pure commodity derivative solution, everything else held constant.

However, it should be noted that in reality, linear correlation only provides a picture of average linear dependence between variables. In order to accurately capture relationships between weather and commodity indexes, it may be necessary to consider different dependence structures as represented by copula functions or captured in a fundamental model of an energy market. For instance, natural gas price and daily average temperature may show very low correlation on average, but on extremely cold days, the correlation can be very high[7].

CASE STUDIES

To illustrate the use of pure weather derivatives and weather-contingent commodity derivatives, we consider three case studies.

Case Study 1

The first case study illustrates the use of a pure weather derivative as a wind speed hedge. The challenge is to protect a wind energy construction company against the financial risk of schedule delays due to high wind speed during installation of turbines. While high wind speed is good for energy generation, it constitutes a safety hazard during the construction phase of a wind farm. For instance, continued presence of high winds (e.g. greater than 10m/s as shown in Figure 5) during the course of an entire work day can lead to work shift cancellation.

A pure weather derivative solution for financial risk exposure arising from this problem is illustrated in Table 3. The structuring process follows the steps shown in Figure 6 but without step 2 i.e.

$$\left.\begin{aligned} Payoff = N \ & if\ I \geq IS \\ 0 \ & otherwise \end{aligned}\right\} \tag{4}$$

where

I is wind speed index , IS is high wind speed threshold and N is Notional (fixed amount).

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[7] In this case, instead of using monthly or seasonal weather indexes as the underlying of a weather contract, a daily (or intra-day) index may be more appropriate.

Figure 5: Wind Speed and Construction Schedule Delay at a Wind Farm in West Virginia

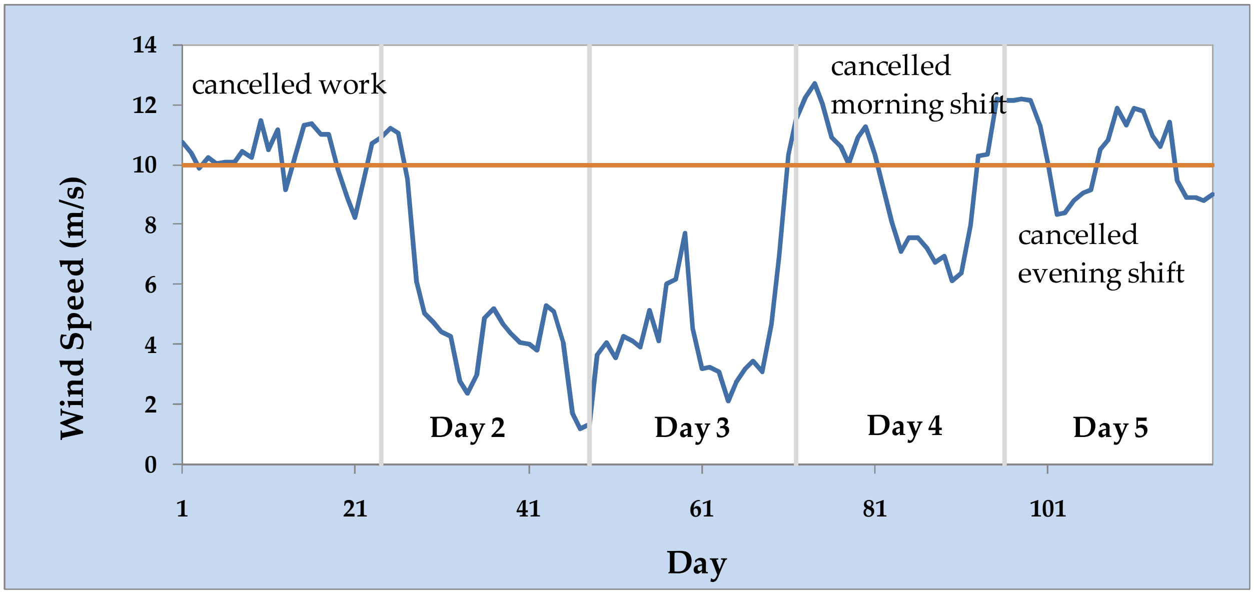
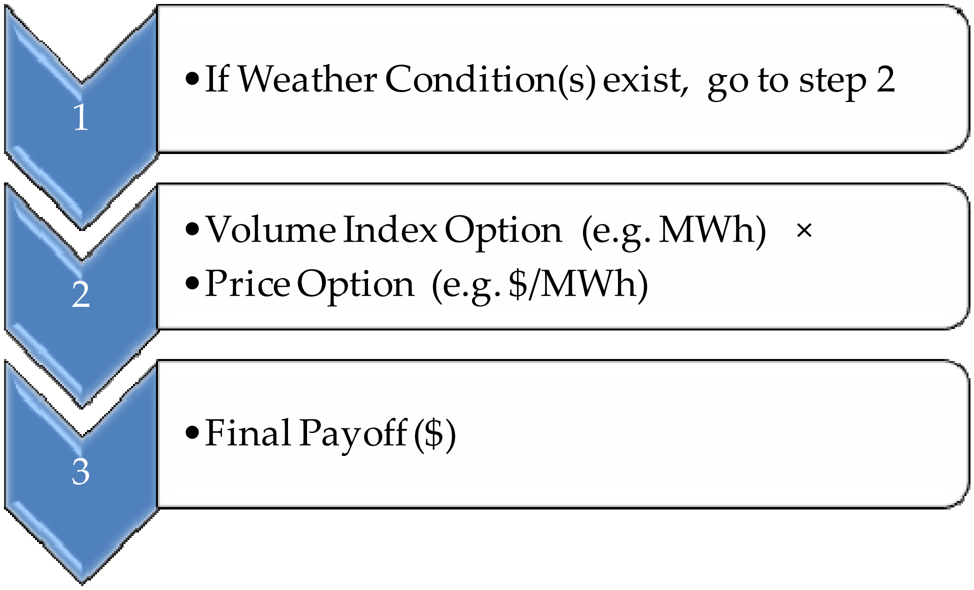


Table 3: Case Study 1 –Coverage against High Wind

Product	Wind Speed Derivative
Buyer	Hedger ABC
Location	West Virginia, United States
Seller	Nimbus Weather Fund LLC
Risk Period	4 Months
Weather Variable	Hourly Average Wind Speed (m/s)
Reference Weather Station	Onsite
Derivative Structure	Call
Cash Settlement Amount (CSA)	$CSA = max\left(\sum_{i=1}^{n} DP_i - Deductible\,, 0\right)$ • where DP is Daily Payout • if $CSA > 0$, Seller Pays Buyer
Cash Settlement Limit (CSL)	USD 750,000
Daily Payout	$DP = a\ fixed\ Notional\ amunt\ (USD)$ for every High Wind Day (HWD)
High Wind Day	Each calendar day when Hourly Average Wind Speed is greater than Wind Trigger

Figure 6: Structuring Steps of a Critical Weather Day Derivative



Case Study 2

The second case study illustrates the use of a weather-contingent commodity derivative as a wind/power hedge. The challenge is to protect the financial risk of a retail electric utility contracted to receive some of its energy supply from a wind farm. In a volatile electricity market, unavailability of expected output from the wind farm exposes the utility to high cost of buying replacement power from the spot market. Given that wind speeds exhibit diurnal and seasonality characteristics, the risk is greater in certain seasons and during certain parts of the day than others (sees Figures 7 and 8).

A weather-contingent power call solution for the hedger is illustrated in Table 4. The structuring process follows the steps shown in Figure 9 whereby wind speed is converted to energy output using a wind power curve (as illustrated in Figure 10) i.e.

$$V = f(I) \tag{1}$$

where the function f in this case is a non-linear relationship between wind speed and electricity output[8]. $Payoff$ is specified as follows:

$$Payoff = \left(max(V - VCS, 0) - max(VPS - V, 0)\right) \times max(C - CS, 0) \tag{5}$$

i.e. a collar on production output multiplied by power price call. The parameters are defined as follows:

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[8] i.e. manufacturer supplied turbine wind-power curve

V = energy output in MW (as converted from power curve)

VCS = Volume Call Strike i.e. cap on energy output

VPS = Volume Put Strike i.e. floor on energy output

C = Commodity Index i.e. spot power price ($/MWh)

CS= Commodity Index Call Strike i.e. strike on spot power price

The payoff of the structure is calculated every half-hour in order to capture diurnal and seasonality patterns of wind speed.

Figure 7: Diurnal Pattern of Wind Speed at a Wind Farm site in New South Wales, Australia

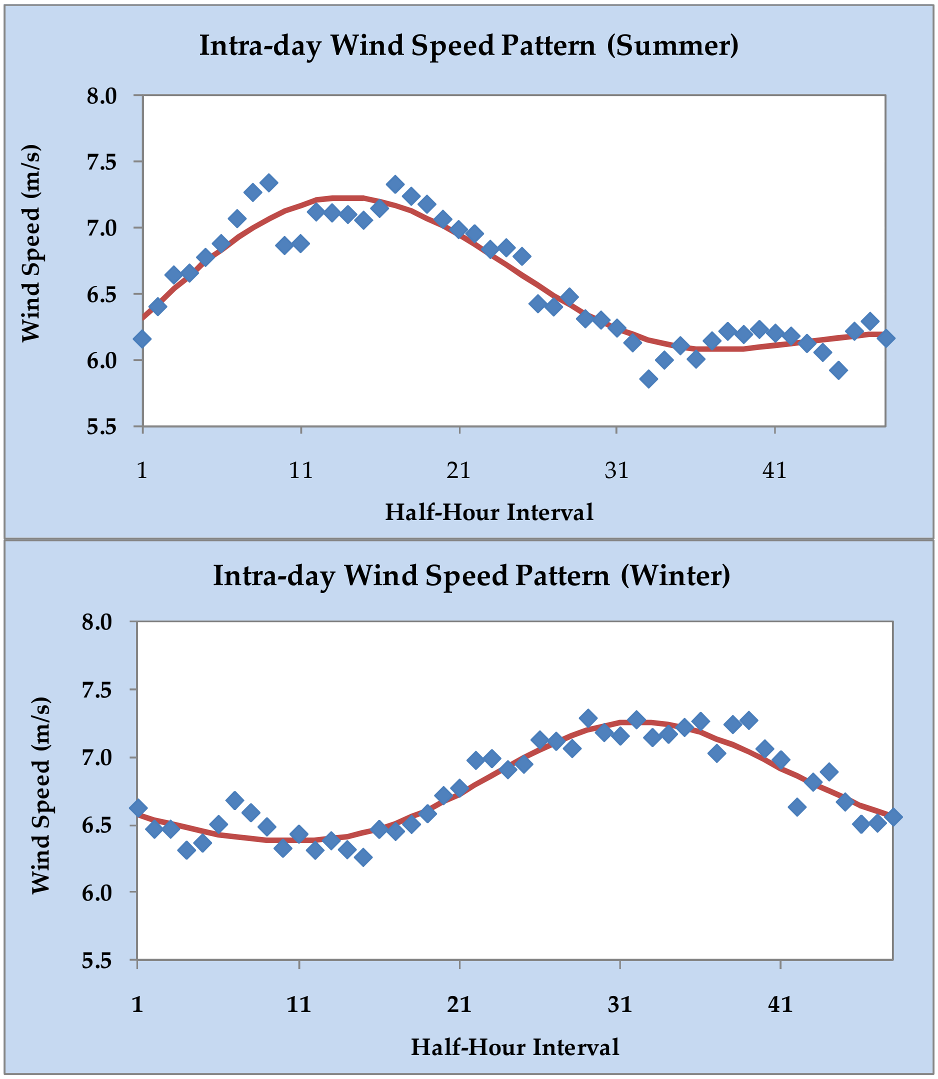


Figure 8: Seasonality of Wind Speed at a Wind Farm in New South Wales, Australia

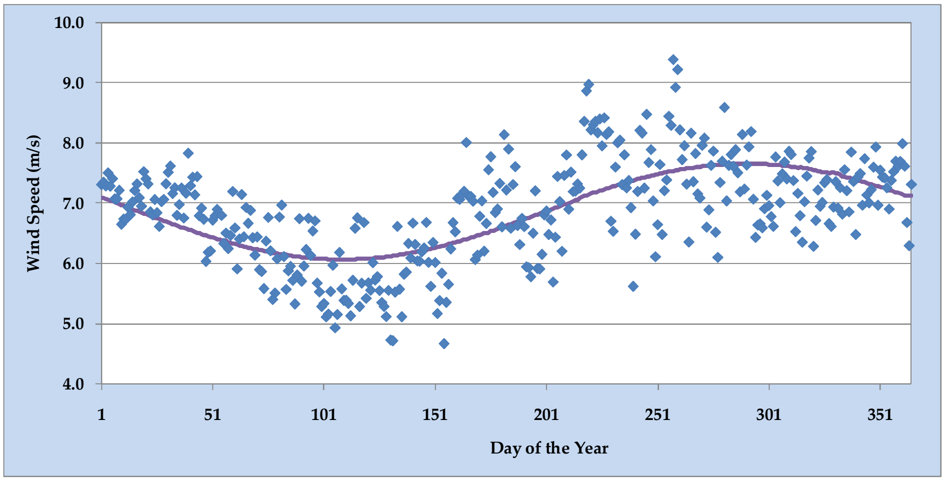


Table 4: Case Study 2 – Coverage against Low Wind Generation and High Power Price

Product	Wind Speed Derivative
Buyer	Hedger XYZ
Seller	Nimbus Weather Fund LLC
Risk Period	5 Months
Weather Variable	Half-hourly wind speed (m/s)
Reference Weather Station	Onsite
Derivative Structure	Collar
Cash Settlement Amount (CSA)	$$CSA = \sum_{i=1}^{n} HHP_i$$ • where HHP is Half-Hourly Payouts • if CSA < 0, Seller Pays Buyer • if CSA > 0, Buyer Pays Buyer • n = number of hours in risk period
Cash Settlement Limit (CSL)	AUD 15,000,000
Daily Payout	$$HHP = \left(max(PG - PGC, 0) - max(PGF - PG, 0)\right) \times max(PI - PS)$$ where • PG= Proxy Generation (MWh) i.e. wind speed converted to energy output • PGC= Proxy Generation Cap • PGF= Proxy Generation Floor • PI= Power Price Index • PS= Power Price Strike

Figure 9: Structuring Steps of a Weather-to-Volume Weather Day Derivative

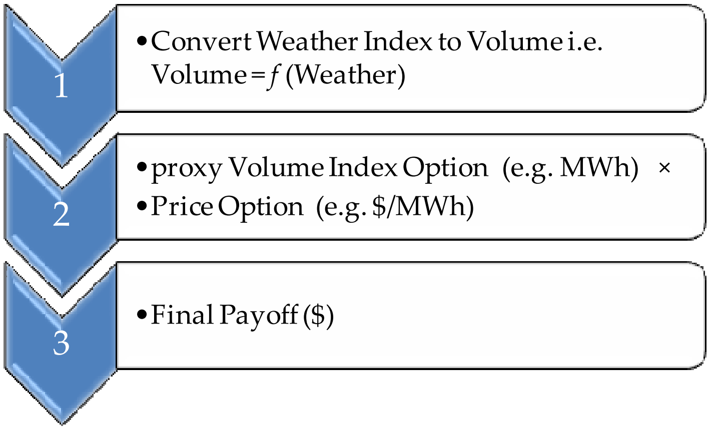
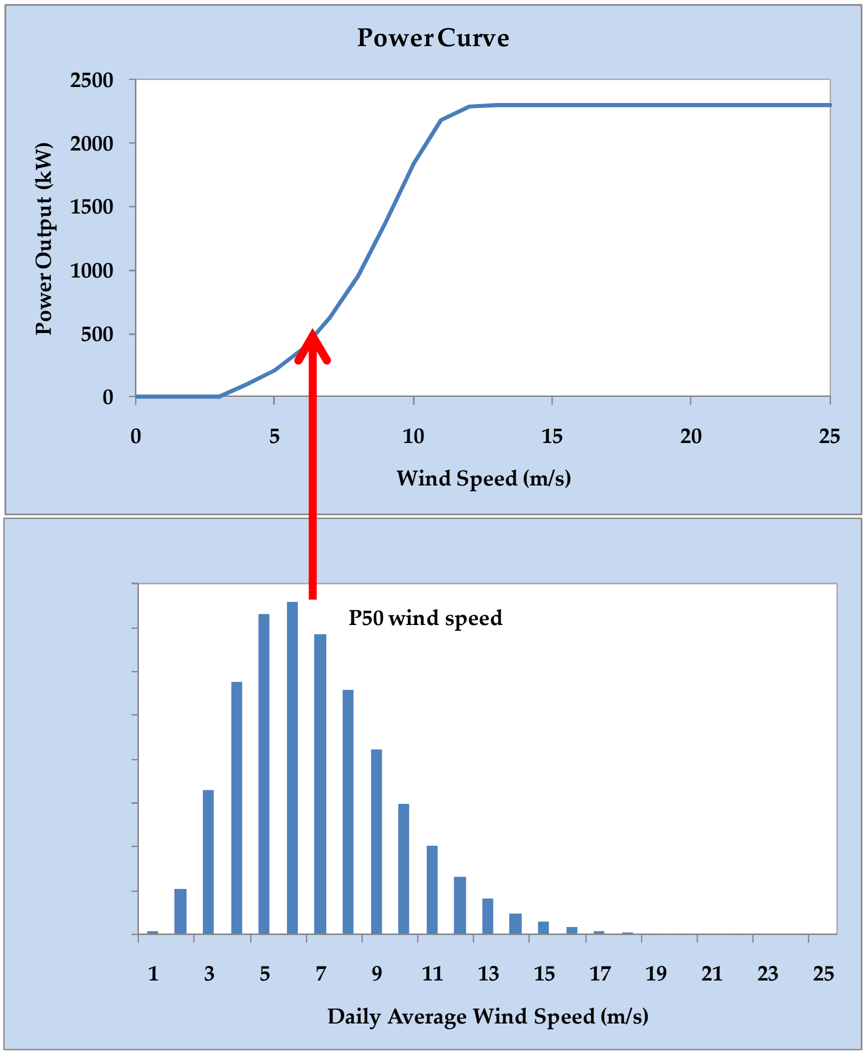


Figure 10: Power Curve Conversion of Wind Speed to Power



Case Study 3

The third case study illustrates the use of a weather-contingent commodity derivative as a temperature/power hedge. The challenge is to protect a retail electric utility against the high cost of meeting supply shortfall from spot electricity markets during periods of heat waves. To illustrate the problem, Figure 11 shows actual evolution of temperature, power demand and spot price during a five day period in January 2009. The figure shows half-hourly Temperature at Melbourne Victoria, plotted against the Australia Electricity Market Operator's (AESO) regional reference price and demand for Victoria. As shown, as temperature deviates significantly from normal, creating a series of heat waves, electricity demand responded by ramping up significantly relative to normal, resulting in a number of periods with power price spikes.

A weather-contingent power call option solution for this type of risk exposure is illustrated in Table 5. The structuring process follows the steps shown earlier in Figure 6 whereby:

$$Payoff = \left.\begin{matrix} max(V - VS, 0) \times max(C - CS, 0)\ if\ I \geq IS \\ 0 \qquad\qquad\qquad\qquad\qquad\qquad otherwise \end{matrix}\right\} \tag{6}$$

i.e. half-hour payoff is derived by multiplying a call option on demand with a call option on spot power price. The parameters are defined as follows:

V = electricity demand in MW (regional demand)

VS = electricity demand strike in MW[9]

C= electricity price in MW

I= temperature index

IS= critical day temperature trigger

CONCLUSION

The use of weather and weather-contingent derivatives provides many businesses with innovative and effective solutions for transferring financial risks related to weather and climate. Available solutions, like those discussed in this paper, are customizable to create bespoke, OTC risk transfer solutions for end users. This helps to reduce basis risks, increase hedge effectiveness and minimize cost.

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[9] The strike is set to reflect the hedger's share of the regional market

Figure 11: Response of Electricity Demand and Price to Heat Wave in Victoria, Australia

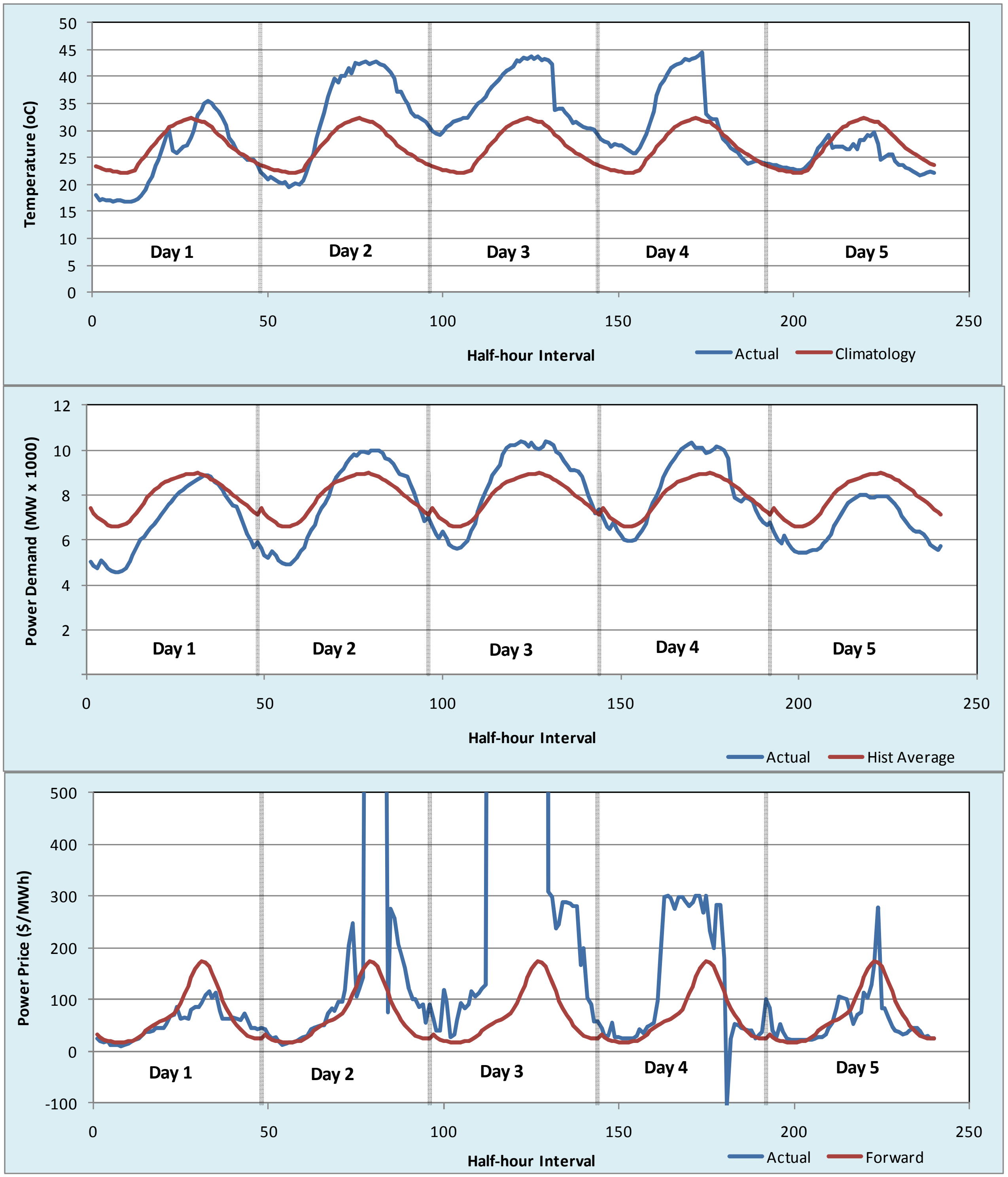

Table 5: Case Study 3 –Temperature and Load Contingent Power Quanto

Product	**Temperature & Load Contingent Power Calls**
Buyer	**Hedger ABC**
Seller	**Nimbus Weather Fund LLC**
Risk Period	**5 Months**
Weather Variable	**Half-hourly wind speed (m/s)**
Reference Weather Station	**Multiple Locations, Australia**
Derivative Structure	**Call**
Cash Settlement Amount (CSA)	$CSA = \sum_{i=1}^{n} HHP_i$ • where HHP is Half-Hourly Payouts • if $CSA > 0$, Seller Pays Buyer • if $CSA < 0$, Buyer Pays Buyer • n = number of hours in risk period
Cash Settlement Limit (CSL)	**AUD 75,000,000**
Daily Payout	**If Maximum Daily Temperature (MDT) ≥ TS** $HHP = max(PI - PS, 0) \times max(LI - LS, 0)$ **otherwise,** $HHP = 0$ **where** • PI = Power Price Index ($/MWh) • PS = Power Price Strike ($/MWh) • LI = Load Index (MWh) • LS = Load Strike(MWh) • TS = Temperature Strike(^{o}C)