Università Ca'Foscari Venezia

Master's Degree Programme in Global Development and Entrepreneurship

Curricula of Global Markets

Final Thesis

Weather Derivatives

How to tackle Climate Change through finance

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Academic Year
2022 / 2023

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INTRODUCTION

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INTRODUCTION

One of the main goal of human civilization has always been to govern nature by defending itself from external threats and tackling exogenous events in order to pursue organized economic activities. One of the biggest source of these events is the weather.

Since the beginning of the new millennium, and especially over the last decade, weather conditions have started coming back to prominence of economics and society, as unusual and hazardous climatic events due to climate change are already causing disruption to many economic activities, and they might become the “casus belli” of conflicts in the near future.

Even though it has been proven by many economists, such as Acemoğlu and Robinson (2012) in their book “Why Nations fail”, that endogenous factors such as political and economic institutions are the main drivers of a country’s economic prosperity, weather phenomena still affect a wide range of economic activities, stretching from primary ones such as agriculture but also to services such as tourism and transportation. According to Pierre Saint-Laurent, full-time finance lecturer at HEC Montréal and associate of the Canadian Derivatives Institute., nearly one-third of the world's GDP is affected by the climate. (The Canadian Derivatives Institute, 2021).

As governments and international organizations are now committing to tackle climate change by acting policies aimed to reduce greenhouse gases emissions to limit the temperature growth to 1.5 °C, as agreed in the 2015 Paris Agreement, companies and people around the world can tackle weather – related costs and losses by using a pretty recent type of financial tools named weather derivatives.

The objective of this paper is to analyze whether weather derivatives can be a useful financial tool for businesses to hedge against weather related losses and whether they can become a mainstream hedge risk instrument in the financial world.

The first chapter of the thesis will give a brief description of financial derivatives.

The second chapter will explains what weather derivatives are and what makes them different from ordinary derivatives, how they work through theoretical examples and the markets in which they are traded.

Chapter number three will describe the method of pricing of these instruments.

Finally, the fourth and last chapter of the thesis is aimed at giving an answer to the initial question, explaining why business and companies of weather – sensitive economic sectors such as energy and agriculture should add weather derivatives in their financial portfolio, by describing some real case studies of the use of weather derivatives and papers taken from the literature which analyzed their potential use.

Moreover, we will also analyze the gains of using them instead of traditional hedge risk instruments such as insurances and the drawbacks regarding their use, explaining why they are still not established instruments in the world of finance.

I. DERIVATIVES

1. 1 Derivatives: a brief definition

Derivatives are financial contracts whose value is linked to the value of an underlying asset. This underlying asset can be, to name a few, an index, the price of a commodity, currency rate or interest rate, and this asset along with its volatility determines the price of the derivatives. They are complex financial instruments that are used for various purposes, including speculation, hedging and getting access to additional assets or markets. Users of derivatives include hedgers, arbitrageurs, speculators and margin traders. Derivatives are traded over-the-counter bilaterally between two counterparties but are also traded on exchanges. (Loo, 2023)

In this thesis, we will focus on derivatives in which their value is linked to weather indexes, called Weather Derivatives.

1.2 Types of derivatives

Derivatives contracts can be categorized into four types:

- Futures
- Forwards
- Options
- Swaps.

1.2.1 *Futures*

Futures are derivative financial contracts that obligate parties to buy or sell an asset at a predetermined future date (maturity date) and price. The buyer (which opens a so-called *long position*) must purchase and the seller (which opens a so-called *short position*) must sell the underlying asset at the set price, regardless of the current market price at the expiration date. At the expire date, the contract can be executed in two ways:

- PHYSICAL DELIVERY of the underlying asset from the seller to the buyer at the predetermined price. This happens mostly when the underlying (for example, a commodity) is used by the company for production.
- CASH SETTLEMENT, meaning that one party will pay the other the difference between the agreed price at the beginning and the current price at the expire of the contract. If the current price is higher, the seller will pay the buyer the

difference, while if the current price is lower, the buyer will pay the seller the difference. This scenario is pretty common with speculators, which want to gain from price fluctuations in time. (Fernando, 2023)

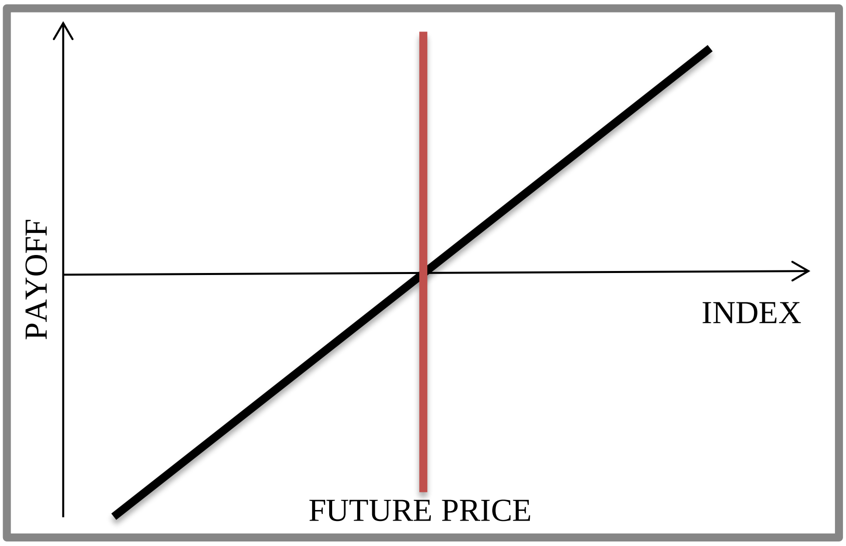
In a future, the payoff formula of an holder (the part who agrees to "buy" the weather index) is the following:

Table 1: Payoff function for an holder of a future by scenario.

SCENARIO	RESULT	PAYOFF FORMULA
Index > Future Price	GAIN	Tick * (Index – Future Price)
Index < Future Price	LOSS	Tick * (Future Price – Index)

Source: Personal elaboration

Graph 1: Payoff function of an holder of a future.



Source: Personal Elaboration

1.2.2 *Forwards*

Forwards contracts are similar to futures contracts in the sense that the holder of the contract possesses not only the right but is also under the obligation to carry out the contract as agreed. While the payoff formula and the types of executions at expire are the same, forwards contracts are exclusively over-the-counter products, which means they are not regulated and are not bound by specific trading rules and regulations, while futures on the other hand are only traded in regulated markets. Since such contracts are unstandardized, they are customizable to suit the requirements of both parties involved.

Given the bespoke nature of forward contracts, they tend to be generally held until the expiry and delivered into, rather than be unwound. (Loo, 2023)

1.2.3 *Options*

Options are financial derivative contracts that give the buyer the right, but not the obligation unlike futures, to buy (call option) or sell (put option) an underlying asset at a specific price (referred to as the strike price) during a specific period of time. Options can be distinguished in two types, based on the time the holder has the right to exercise.

- AMERICAN OPTIONS, which can be exercised at any time before the expiry of its option period,
- EUROPEAN OPTIONS, which can only be exercised on its expiration date.

To enter into an option contract, the buyer, the so called *holder* which opens a long position, has to pay the seller, the so called *writer* which opens a short position, a sum of money called *premium.*

Regarding the payoff of options, the holder of the call option will receive the difference between the spot price (the current price of the underlying) and the strike price, while the holder of a put option will receive the difference between the strike price and the spot price. These differences between prices take the name of *intrinsic value,* which is the main feature which determines the so called *moneyness* of an option. There are three types of moneyness:

- *In-the-money:* The option has intrinsic value, meaning that exercising the option will have positive results but not necessarily a profit, because of the premium paid in advance.
- *At-the-money*: the strike price is equal to the spot price of the underlying.
- *Out-of-the-money*: The option does not have intrinsic value, meaning that the buyer will not exercise the option because a loss of money will occur. (Chen, 2023)

Like futures, the execution of options contract can result in a physical delivery of the underlying from the seller to the buyer at the predetermined price or just through cash settlement, in which one party pays the other the difference between the strike and the spot prices. (Fernando, 2023)

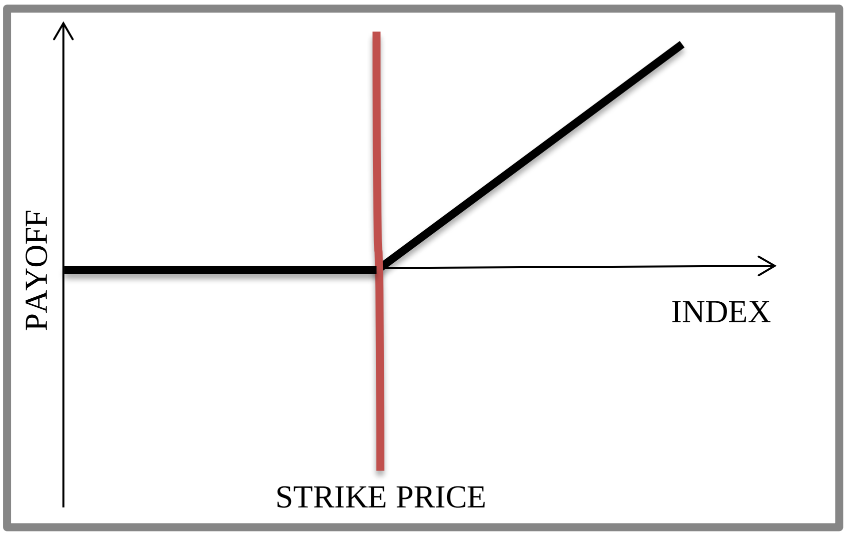
Table 2 and table 3 show the payoff formula of a call option and a put option respectively, while the payoff function for an holder of a call option is shown in graph 2 and the payoff function for an holder of a put option is shown in graph 3.

Table 2: Payoff function of an holder of a call option by scenario.

SCENARIO	MONEYNESS	PAYOFF FORMULA
Index > Strike	In the money **	Tick * (Index – Strike)
Index < Strike	Out of the money	0
** In order for the holder to exercise a profit, the payoff must be higher than the premium paid in advance		

Source: Personal elaboration

Graph 2: Payoff function of an holder of a call option.



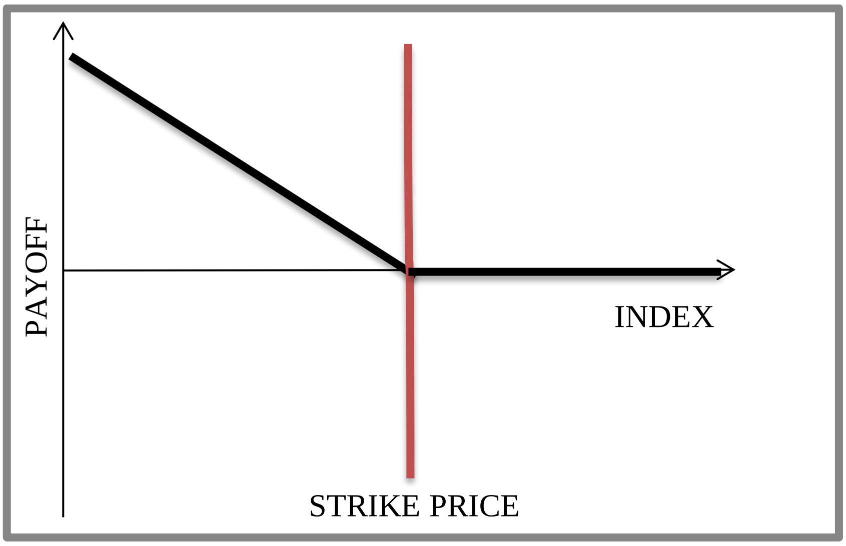
Source: Personal elaboration

Table 3: Payoff function for an holder of a put option by scenario.

SCENARIO	MONEYNESS	PAYOFF FORMULA
Index < Strike	In the money **	Tick * (Strike - Index)
Index > Strike	Out of the money	0
** In order for the holder to exercise a profit, the payoff must be higher than the premium paid in advance.		

Source: Personal elaboration

Graph 3: Payoff function for an holder of a put option.



Source: Personal elaboration

1.2.4 *Swaps*

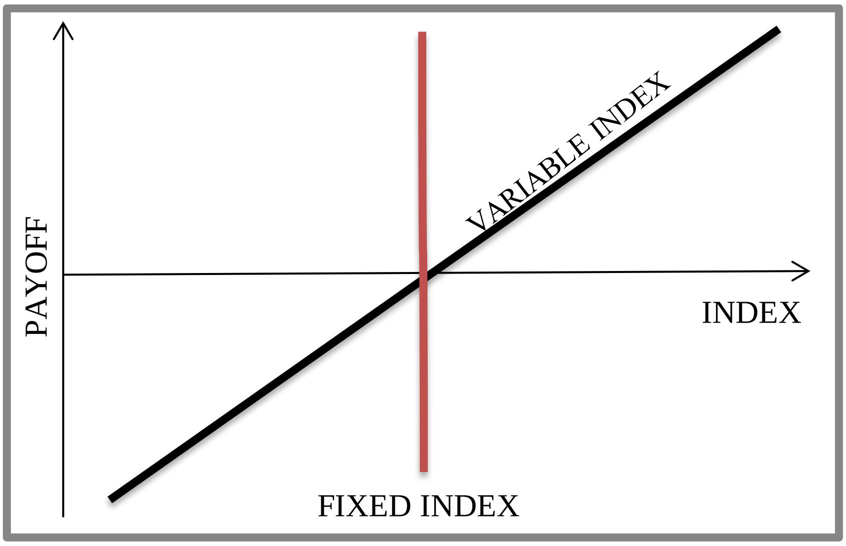
Swaps are derivative contracts that involve two holders, or parties to the contract, to exchange financial obligations. One obligations is usually fixed, while the other is variable and based on a benchmark value. Interest rate swaps are the most common swaps contracts entered into by investors, in which the first part pays the second a fixed interest rate, while the second pays the first an interest rate based on a benchmark rate (for example, LIBOR or EURIBOR). (Chen, 2023). They are exclusively traded over the counter and not on the exchange market, because of the need for swaps contracts to be customizable to suit the needs and requirements of both parties involved. As the market's needs have developed, more types of swaps have appeared, such as credit default swaps, inflation swaps and total return swaps. (Loo, 2023)

Table 4: Payoff function fof the party which pays the other the fixed value of a swap by scenario:

SCENARIO	RESULT	PAYOFF FORMULA
Variable Index > Fixed Index	LOSS	Tick * (Variable Index – Fixed Index)
Variable Index < Fixed Index	GAIN	Tick * (Fixed Index – Variable Index)

Source: Personal elaboration

Graph 4: Payoff function of an holder of a swap.



Source: Personal elaboration

1.3 Combinations of options

When it comes to the trade of options, combinations require the use of more than one derivative contracts. These combinations can be simple, with only two contracts types, such in the case of *collars*, *straddles* and *strangles,* but more complicated types of combinations also exist, such as *iron condor* and *butterfly condor.* We will analyze the simple combinations.

1.3.1 Collars

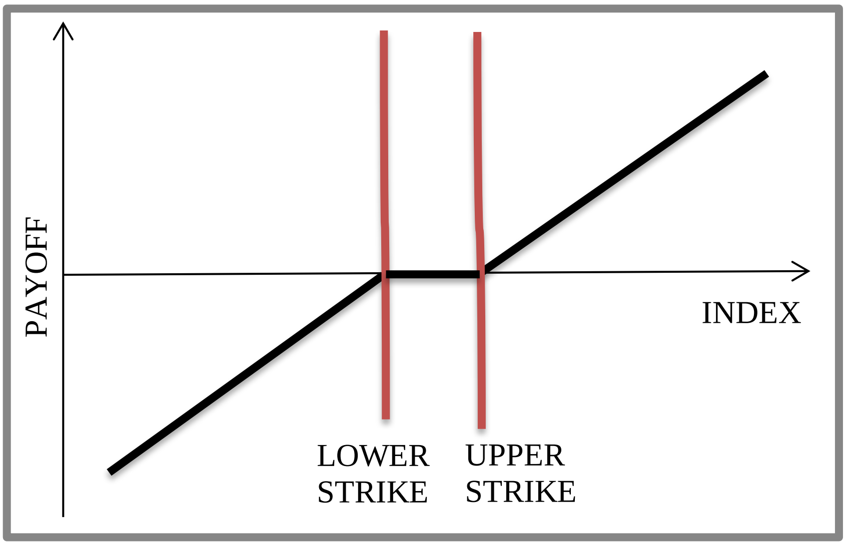
A Collar is a financial transaction which consists in the simultaneous purchase of a upside Call Option and the sale of a downside Put Option. These option usually have the same tick but two different strikes for the call option and for the put option. (Ganti, 2022) Table 5 shows the results and the payoff formula for the holder of a collar by each scenario. The strike of the put option is called “Lower strike” while the strike of the call option is called “Upper strike”. As collar requires the simultaneous sale and purchase of two different options, the collar is free of charge because the premium paid for the call is covered by the premium received from the put.

Table 5: Payoff function of an holder of a collar by scenario.

SCENARIO	RESULT	PAYOFF FORMULA
Index < Lower Strike (of the put)	LOSS	Tick * (Index – Lower Strike)
Lower Strike (of the put) < Index < Upper Strike (of the call)	NO EXERCISE	0
Index > Upper Strike (of the call)	GAIN	Tick * (Upper Strike – Index)

Source: Personal elaboration

Graph 5: Graphical payoff of an holder of a collar.



Source: Personal elaboration

1.3.2 Straddles

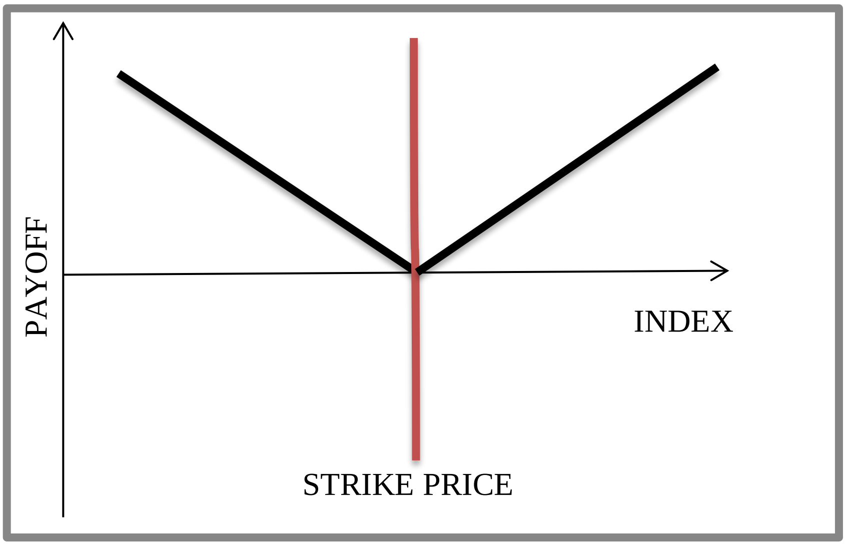
A straddle is a neutral options strategy that involves simultaneously buying both a put option and a call option for the underlying security with the same strike price and the same expiration date. The call will pay out if the index is above the strike, while the other will pay out if the index is lower than the strike. Therefore, through a straddle one of the two options will certainly be exercised, but as for all options, the payoff must be higher than the premium paid in advance in order for the holder to have a positive return in its straddle transaction. (Chen, 2023) Table 6 shows the formula of the payoff for the holder of the straddle by each scenario.

Table 6: Payoff function of an holder of a straddle by scenario, and which of the two options will be exercised.

SCENARIO	OPTION EXERCISED	PAYOFF FORMULA
Index < Strike	PUT **	Tick * (Strike - Index)
Index > Strike	CALL **	Tick * (Index – Strike)
** In order for the Call or the Put to be profitable, the payoffs must be higher than the premium paid in advance.		

Source: Personal elaboration

Graph 6: Graphical function of an holder of a straddle.



Source: Personal elaboration

1.3.3 Strangles

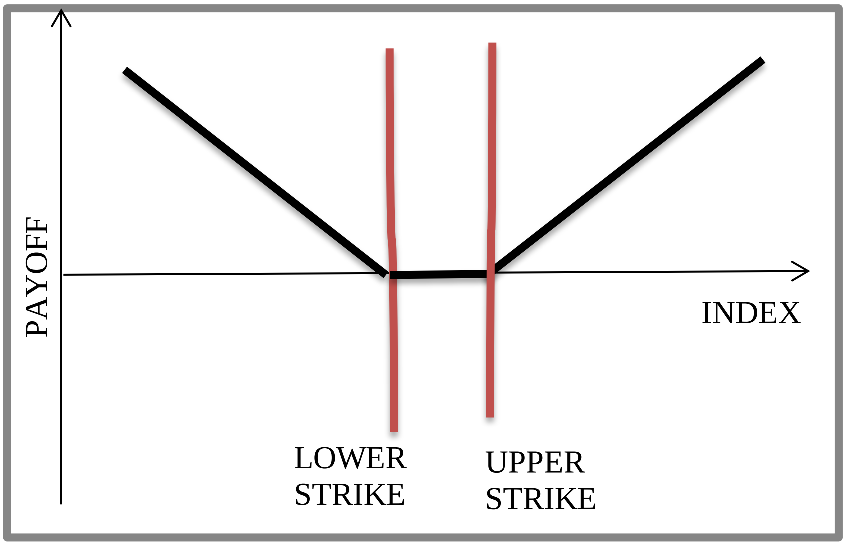
Strangles work almost similarly like straddle, with the only difference that while the strike and the call and put options of a straddle are the same, in the strangle the strikes are different (lower strike for the put and an higher strike for the call). Therefore there is a possibility in a strangle that both the two options will not be exercised if the index falls between the two strikes, unlike straddles, in which one of the two options will certainly be exercised. For these reason strangles are usually a cheaper opportunity than straddles because of the lower probability that they might be effective if the index is not enough high or low. (Hayes, 2022).

Table 7: Payoff formula of an holder of a strangle by scenario.

SCENARIO	OPTION	PAYOFF FORMULA
Index < Lower Strike	PUT **	Tick * (Index – Lower Strike)
Low Strike < Index < Upper Strike	NO EXER.	0
Upper Strike < Index < Upper Limit	CALL **	Tick * (Upper Strike – Index)
*In order for the Call and the Put to be profitable, the payoffs must be higher than the premiums paid in advance. If none of the two options are exercised, the strangles will result in a loss for the holder.		

Source: Personal elaboration

Graph 7: Graphical payoff function of an holder of a strangle.



Source: Personal elaboration

II. WEATHER DERIVATIVES

2.1 A brief history of Weather Derivatives

The first weather derivative contract was a power contract created in the summer of 1996 between two American companies, Aquila Energy and Consolidated Edison Company. The terms of the contract were that Aquila Energy sold power to Consolidated Edison Company with the agreement that if the temperature was less than expected during the period of the contract, (thus requiring a lesser use of air conditioning and smaller overall power consumption) Aquila Energy would pay Consolidated Edison Co. a rebate. (Considine, 2004) In 1997, weather derivatives started being traded over the counter in unregulated markets and two years later in 1999, to further increase the size of the weather derivatives market and to remove the counter-party credit risk involved in over-the-counter weather contracts, the Chicago Mercantile Exchange (CME), the most famous market for financial derivatives, introduced the first exchange-traded, temperature-related weather futures and options. (Jones, 2007)

In 1999, the Weather Risk Management Association (WRMA) was founded as a trade association representing the global market of weather risk management professionals. WRMA's major contributions to the development of the weather risk market include standardization, market expansion and access enhancement.

2.2 A brief definition of Weather Derivatives

Weather Derivatives are financial instruments whose value and/or cash flows depend on the occurrence of some meteorological events, which are easily measurable, independently authenticable, and sufficiently transparent to act as triggering underlying for financial contracts. (Barrieu, Scaillet, 2008)

Weather Derivatives can take the form of the types of derivative previously described such as futures, forwards, options or swaps. The main difference with regular financial derivatives is that and the underlying asset to which they are linked is a weather parameter like temperature, rainfall or daily sunlight, which value is measured by a predetermined index which differs depending on the location and the source of data. However, it is possible to notice that weather is not tradable, and it is not something that you can buy or sell or something that has an intrinsic value. Weather derivatives

constitute for this reason an incomplete market and therefore the word “derivative”, associated with these financial products, may sound misleading. (Bianconi, 2020)
Moreover, as weather is not something tangible like a commodity, weather derivatives can only be executed between the parties through cash settlement, meaning that one party will pay the other the difference between the “strike”, which is the case of weather derivatives is the agreed level of the weather parameter or index, and the spot price, which is the registered index over the lifetime of the contract.
Weather derivatives are used by companies and individuals to hedge against the risk of weather – related losses and as a part of their risk – management strategy. The profitability and revenues of virtually every industry—agriculture, energy, entertainment, construction, travel, and others—depend to a great extent on the vagaries of temperature, rainfall, and storms. Unexpected weather rarely results in price adjustments that entirely make up for lost revenue, making weather derivatives securities that allow companies to hedge against the possibility of weather that might adversely affect their business a pivotal investment for many. (Hussain, 2020
According to The Canadian Derivatives Institute (2021), nearly one – third of the global economic output is affected by weather conditions.

2.3 Weather Indexes

As we mentioned previously, the underlying asset, a weather phenomenon, takes the form of a weather index and can be classified according to each.. Here are some of the weather indexes weather derivatives are linked to, according to each climatic condition:

- TEMPERATURE: Heating Degree Days (HDD) used in winter, Cooling Degree Days (CDD) used in summer and Cumulative Average Temperature (CAT)
- PRECIPITATION: Daily rainfall in mm or inches in a particular place, Daily snowfall and snowpack in mm or inches
- WIND: Wind speed
  (Bianconi, 2020)

2.4 Temperature Indexes

As weather derivatives which have temperature indexes such Degree Days and Cumulative Average Temperature as underlying asset make up 95% of all contracts (Bianconi, 2020), this thesis will focus on these types of weather indexes and their derivative contracts.

2.4.1 Degree Days: Heating Degree Days (HDD) And Cooling Degree Days (CDD)

A Degree Day is a measure of how much a day's average temperature deviates from 65 degrees Fahrenheit (or 18 degrees Celsius), a baseline selected by utility companies since furnaces and air conditioners are turned on above and below this benchmark.
The average daily temperature is defined as the average of a day's maximum and minimum temperature.

Daily Average Temperature Formula: (Maximum Temperature of the day – Minimum Temperature of the day)/2

They are classified between Heating Degree Days (HDDs), when the average temperature is below 65°F (18°C) and Cooling Degree Days (CDDs), when it is above 65°F (18°C).

Heating Degree Days (HDD) is the difference between the 65°F (18°C) benchmark value and the average temperature observed in a day. HDD cannot be a negative number.

Daily HDD Formula: 65°F (18°C) Base temperature – Daily Average Temperature

Cooling Degree Days (CDD) is the difference between the average temperature observed during the day and the 65°F (18°C) benchmark. CDD also cannot be a negative number. The formula to calculate the CDDs in a day is the following:

Daily CDD Formula: Daily average temperature – 65°F (18°C) Base temperature
(Jones, 2007)

For example, if the average temperature of a day in October is 14 °C, the HDD for that day will be: 18-14=4. If the average temperature is 20, HDD cannot be negative, because above 18°C there is no need to heat, so HDD=0.
On the other hand, if the average temperature of a day in June is 25°C, the CDD for that day will be 25 – 18 = 7. If the average temperature is 16, CDD cannot be negative, because under 18°C there is no need to cool, so CDD=0.

2.4.2 Cumulative Average Temperature (CAT)

The Cumulative Average Temperature (CAT) index is the accumulation of daily average temperatures over a calendar month, with the accumulation period beginning on the first calendar day of the contract month and ends with the last day of the contract calendar month.

CAT Formula: Σ Daily average temperature in a month

For example, if the average daily temperature for each of the first 15 days of a calendar month was 10°C and the average daily temperature for each of the remaining 15 days was 20°C, the cumulative average temperature (CAT) would equal 450 (= (15 days x 10) + (15 days x 20)). (CME Group Website)

2.5 Examples and features of Weather Derivatives Contracts

Weather Derivatives can take the form of typical derivative contracts such as futures, forwards, options and swaps, but they can also take the form of collars, strangles and straddles, strategies which combine the purchase and/or sell of options. Among these contracts, only futures and contracts are traded in regulated markets, the most famous of which is the Chicago Mercantile Exchange, while the others are all over-the-counter contracts.

Every weather derivative contract is made up of the following features:

- Contract period (generally between one and six months)
- Contract type (future, forward, call or put option and swap)
- An official weather station from which weather measurements are taken
- A weather variable measured at weather station over the contract period
- The strike price (in case of options) or future or forward price (in case of a future or a forward)
- Tick, which is the amount of money paid out for each unit of the index the contract is based on-
- Premium (in the case of an option or combination of options). (Alaton, 2002)

2.5.1 Example 1 – Rainy Days Forward

A water park in Vicenza knows that less rainy summer days will mean more people coming to swim in its pools. Therefore, the owner of the water park wants to hedge against the risk that rainy days could prevent people from spending a day at the water park.

On the other side, a farmer just outside of Vicenza knows that he needs at least 600 mm of water between May and August for his cornfields to produce a sufficient amount of corn cobs. While half of it can be collected through artificial irrigation, the other half must come from natural rainfall. Therefore, he wants to hedge against the risk of low rainfall which can increase irrigation costs and drought.

The two parties meet and decide to stipulate a derivative contract which is going to pay out one of the two parties based on the number of rainy days occurred during a certain period. As the two parties are dealing without the involvement of a regulated market, this type of contract will be a forward. Table 8 shows the features the two parties agreed on.

Table 8: Features of the rainy days future contract between the water park and the corn producer.

RAINY DAYS FORWARD	
BUYER	Water Park
➢ Hedge against	Lower influx of visitors due to excessive number of rainy days in summer
SELLER	Corn producer
➢ Hedge against	Lower production of corn and higher irrigation costs due to drought
LOCATION	Vicenza, Italy
START	01/06/2023
END	31/08/2023
CONTRACT TYPE	Forward
WEATHER INDEX	Number of rainy days in summer
TICK	1000 Euros per day
FORWARD PRICE	18 rainy days with at least 5 mm of rain between 8 a.m. to 1 p.m.

Source: Personal elaboration.

The contract duration of three months between June and September is the period of the year water parks are open to the public and the growing period of corn in Italy, even though the sowing take place one month earlier in May.
The forward price is calculated based on the average number of rainy days between June and August in Vicenza over the last 10 years. According to the National Oceanic and Atmospheric Administration, a US federal agency, this figure has been 18 days. (NOAA, 2023)
The tick is based on the average amount of people entering the water park each day (200 people) which spend an average ticket of 5 Euros. By multiplying the average price each person pays by the number of people entering the park, the figure will be: 200 * 5 = 1000 Euros. (Personal Elaboration)
In the future, the water park owner agrees to "buy" the number of rainy days accumulated during the summer, while the farmer agrees to "sell" the number of rainy days during the summer. once the contract expires.
Therefore, the buyer will gain on the future position if the number of rainy days accumulated during the lifetime of the contract is above the strike, and he will receive the money from the seller, because he will "buy rainy days" at a lower price than the strike. The formula of the payoff of the contract for the buyer is:

*PAYOFF OF THE BUYER = 1.000 Euros * (Index –Forward Price (18 rainy days))*

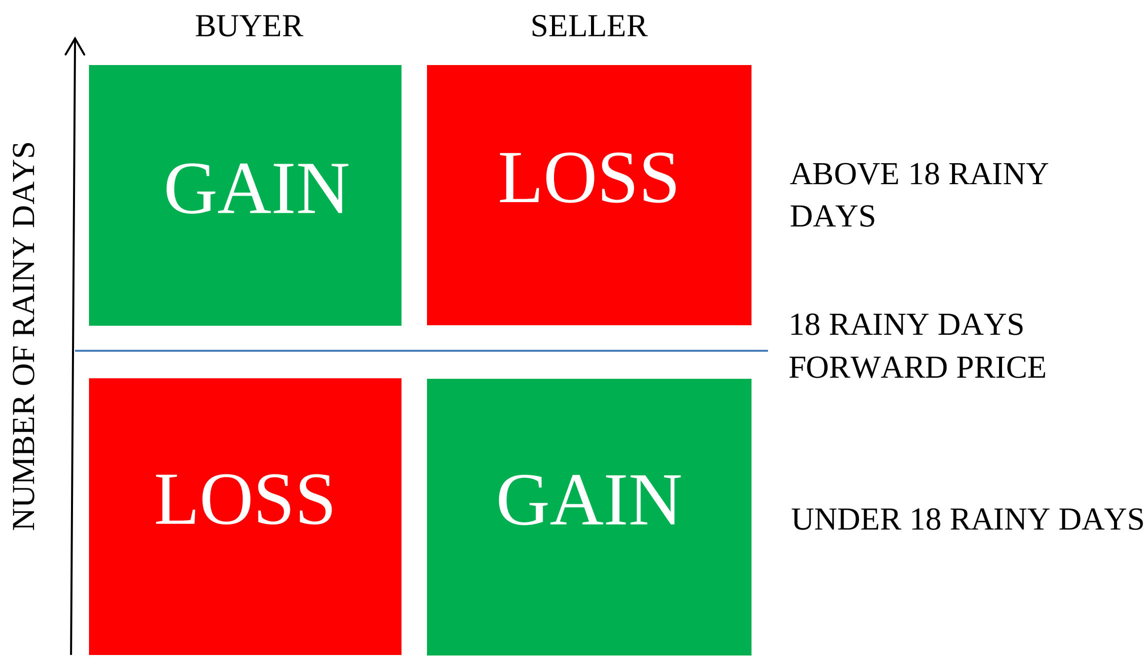
Otherwise, if the accumulated number of rainy days is lower than the forward price, the seller will receive the money from the buyer, because he will "sell rainy days" at a higher price than the forward price. The formula of the payoff of the contract for the seller is:

*PAYOFF OF THE SELLER = 1.000 Euros * (Forward Price - Index (18 rainy days))*

The two parties recognized that some problems about the method of measurement of rainy days might occur. In order to prevent controversies about the effective number of rainy days, the two parties decided that the criteria for a day to be considered a "rainy day", a minimum amount of 5 mm between 7 a.m. and 1 p.m. must occur. This is because the corn farmer noticed that people will not go to the water park only if it rains in the morning, while rain only in the afternoon does not affect daily revenues of the water park. Otherwise, days with an accumulated rainfall level of less than 5 mm in the morning will not be considered "rainy days". (Personal elaboration)

For example, if the accumulated number of rainy days between June 1st and August 31st is 22, the water park owner will gain from the future position and he will receive money from the corn producer, which can offset some of the losses incurred because of lower revenues due to rainy days which caused fewer people to spend a day inside the water park. (Personal elaboration)

Graph 8: Scenarios in which the buyer and the seller gain or lose money from the future position.



Source: Personal elaboration

2.5.2 Example 2 – HDD Put Option

The main gas distribution company of Jerusalem, Israel, noticed that over the past 5 years winters have been milder than usual. Therefore, it wants to hedge this risk of lower gas sales due to less need for heating in homes and public buildings in the city.

On the other hand, a kibbutz specialized in the production of oranges just outside of Jerusalem wants the temperature to be between 10°C to 15°C in order for the plants to produce good fruits. The kibbutz knows also that some rain benefits his plants, but snow can create serious damages to the plants, as its weight can break the tree's branches, as well as cold temperatures which do not allow the fruits to grow.

In order to tackle these issues, at the beginning of October 2022 the gas company and some representatives of the kibbutz agreed to stipulate a financial contract to hedge their respective risks.

They decided to stipulate a Put Option contract, in which the gas distribution company agreed to "sell" a number of HDD (Heating Degree Days), which is the weather index chosen by the parties, only if it is lower than the strike level decided. Otherwise, the gas distribution company can decide to not exercise the option. Table 9 describes the features of the contract the two parties decided.

Table 9: Features of a HDD Option between the most important gas distribution company in Jerusalem and a farm specialized in the production of oranges.

HDD PUT OPTION	
BUYER	Gas distribution company
➢ Hedge against	Lower gas sale due to a milder winter than average
SELLER	Farm of the kibbutz
➢ Hedge against	Lower orange production due to a colder winter than average
LOCATION	Jerusalem, Israel
START	01/12/2022
END	29/02/2023
CONTRACT TYPE	Put Option
WEATHER INDEX	Cumulative number of Heating Degree Days between December and February.
TICK	75 Shekels (or 20 US Dollars) per each HDD above the strike
STRIKE	720 HDD
PREMIUM	6750 Shekels

Source: Personal Elaboration.

The contract duration of three months between December to February is the coldest period of the year in Jerusalem, and also the same period in which the first orange fruits born.

According to the National Oceanic and Atmospheric Administration, the average temperatures in Jerusalem in December, January and February are 11°C, 9°C and 10°C respectively. (NOAA, 2023)

The strike level is calculated using the HDD formula and through the following steps:

- subtracting the average temperature of each month from 18°C, the benchmark temperature for the HDD and the CDD index.
- multiplying the result for the number of days of each month (31 for December and January, 28 for February)
- summing the three results.

The calculation are as follows:

(18–11) * 31 + (18-9)* 31 + (18-10) * 28 = 720 HDD

The chosen tick was the tick used for HDD options and futures traded in the Chicago Mercantile Exchange, which is 20 US dollars, (CME Group Website) converted from USD to Israeli Shekels at the present exchange rate, in which 1 dollar equaled 3.55 NIS. (Bloomberg Website)

The result was 72 shekels, so the parties decided a tick of 75 shekels.

The premium was calculated because the gas distributing company accepted the fact that a 1°C colder than the average temperature, which is the benchmark in order to decide the strike level, will not cause any significant change to the company's revenues. For example, if the average temperature of December is 10°C instead of 11°C, the number of cumulated HDD will be 31, and this figure multiplied by the tick will give a result of: 2325 Shekels only in December. If the do the same calculation for January and February and we sum them up with December, we will obtain a result of 6750 shekels. (Personal elaboration)

In every option, the cost of the premium is inversely proportionated to the strike level. If the strike level was too low, and therefore much easier to overcome in order to get the payoff, the seller will ask for an higher premium. On the other hand, if the premium is too high, and therefore too difficult to reach in order to receive the payoff, the buyer will be willing to pay a lower premium. (Jones, 2007)

In this type of contract, the gas distributing company, which is the holder of the option, agrees to bear the risk of a milder winter than usual by paying an anticipated premium to the farm, which is the writer of the option.

As this is a put option, the gas company will gain on the position if the number of HDDs accumulated during the lifetime of the contract is lower than the strike, because it will “sell HDDs” at an higher price than the agreed strike. The formula of the payoff of the contract for the buyer is:

*PAYOFF = 75 shekels * (Strike (720 HDDs) - Index)*

Otherwise, if the accumulated number of rainy days is lower than the strike, the holder will decide to not exercise the option, and he will only lose the premium paid in advance to the writer. For example, if the accumulated number of HDDs between December 1st and February 28st is 750, the gas company will decide not to exercise the option and only lose the usual winter. (Personal elaboration)

In order for the put option position to be profitable, the payoff must be higher than the 6750 Shekels paid in advance.

We can calculate the break-even point by dividing the premium to the tick and subtracting it to the strike level.

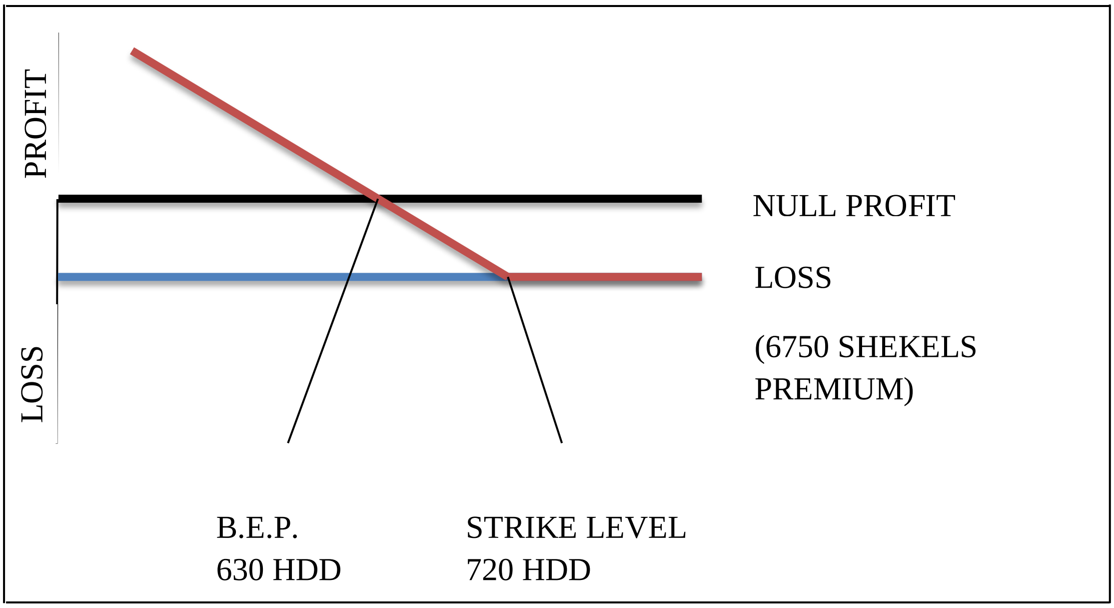
BREAK-EVEN POINT:

INDEX VALUE (in HDDs) = 720 – (6750 / 75) = 630 HDD

TEMPERATURE VALUE (in °C) = 18 – (630 / 90) = 11°C

We can therefore come to the conclusion that, in order for the put option position to be profitable for the writer, the average temperature between December and February must be above 11°C, corresponding to 630 HDDs over the same period.

Graph 9: Payoff function of the Put Option holder (the gas distribution company).



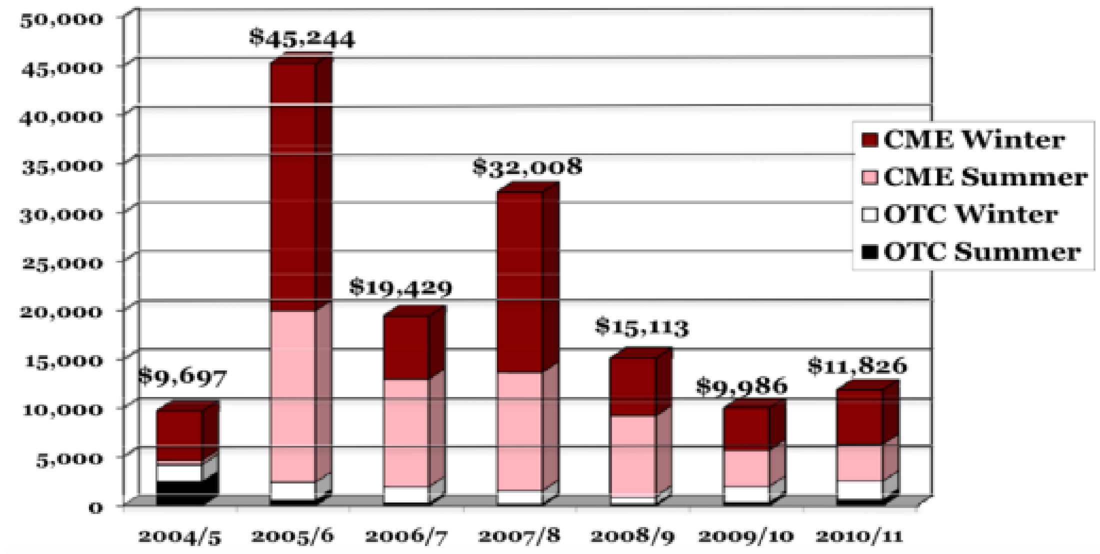
Source: Personal elaboration.

2.6 The Market of Weather Derivatives: Over the Counter (OTC) and the Chicago Mercantile Exchange (CME)

As for all types of derivatives, weather derivatives can be traded in unregulated market, the so called "Over the Counter" (OTC) market, or in regulated market such as the Chicago Mercantile Exchange (CME).

The first types of weather derivatives contracts were traded Over The Counter (OTC). OTC is an unregulated market as the parties act without the involvement of a central exchange or other third parties (Hussain, 2022). In an OTC market, dealers act as market-makers by quoting prices at which they will buy and sell a security, currency, or other financial products. A trade can be executed between two participants in an OTC market without others being aware of the price at which the transaction was completed. The OTC is a better choice than a regulated market for investors who want more tailor – made and less standardized contracts, by deciding the terms of the contracts independently. In fact, as shown in graph 10, the OTC market comprises a larger amount of weather indexes than the CME.

Graph 10: Total value of Weather Derivatives Contracts by season (Winter and Summer) and by type of market (CME and OTC) from 2004 to 2011 (Data in billion US Dollars).



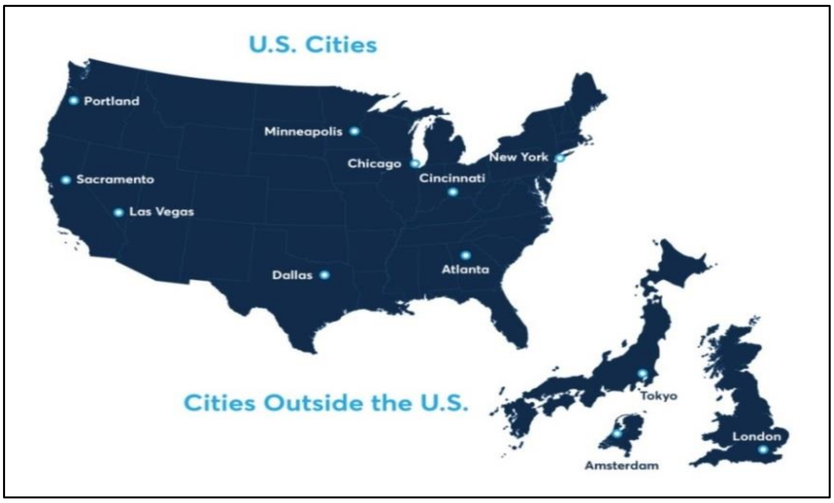
Source: PWC (2011): Weather Risk Derivative Survey. PWC, May, p. 30.

In general, OTC markets are typically less transparent than exchanges and are also subject to fewer regulations. While OTC markets function well during normal times, there is an additional risk, called a counter-party risk, that one party in the transaction will default prior to the completion of the trade or will not make the current and future payments required of them by the contract (Kramer, 2022). Even though the OTC still today represents the biggest share of the overall weather derivatives market (The Canadian Derivatives Institute, 2021), weather derivatives can be bought and sold also in regulated and standardized markets, such as the Chicago Mercantile Exchange (CME).

2.7 Weather Derivatives traded in the CME (Chicago Mercantile Exchange)

In 1999 the Chicago Mercantile Exchange (CME) started listing weather futures and options based on a range of weather conditions in 18 cities in the United States, 9 in Europe and 2 in Asia. These cities were chosen based upon their population, the unpredictability in their seasonal temperatures, and the number of contracts written in the over-the-counter market for each city. As of 2023, the number of cities for which weather derivatives are based on is 12, which are shown on image 1. (Weather Futures and Options, CME Group Website) The CME offers Heating Degree Day (HDD), Cooling Degree Day (CDD) and Cumulative Average Temperature (CAT) futures contracts and options for monthly and seasonal temperature related events. HDD futures and options are traded in two winter seasonal strips: a longer one from October to March and a shorter one from December to February, and they are available for the 9 US Cities and for London and Amsterdam. CDD futures and options are traded in two summer seasonal strips: a longer one from May to September and a shorter one from July to August, and are only available for the US Cities contracts. CAT futures and options are traded in the same winter seasonal strips and summer seasonal strips of HDD and CDD contracts, but are only available for London and Amsterdam in summer and for both season in Tokyo. (Sutton-Vermeulen, 2021)

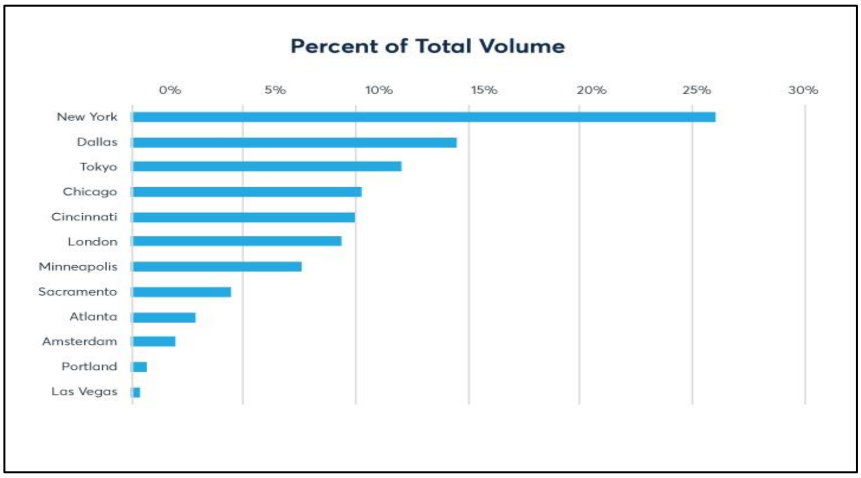
Image 1: Cities in the United States, Europe and Asia for which the Chicago Mercantile Exchange (CME) trades weather futures and options.



Source: Sutton – Vermeulen, 2021, "*Managing Climate Risk with CME Group Weather Futures and Options",* CME Website.

In 2020, the volume of weather futures and options traded in the CME was 750 million dollars, an increase of 60% compared to 2019, while weather options trade showed an increase of 143% during the same period, reaching 480 million dollars. In 2020, over 75,000 weather futures and options have traded at CME, 70% of them in the United States and 15% in both Europe and Asia, as shown in Graph 11, for an overall value of 1.23 billion dollars (Sutton-Vermeulen, 2021). This data is considerably lower than at least 10 or 15 years before. In 2005 in fact the CME traded weather derivatives for a total amount of 4.25 billion dollars, which at that time constituted 56% of the total trade volume worldwide. (Tindall, 2006)

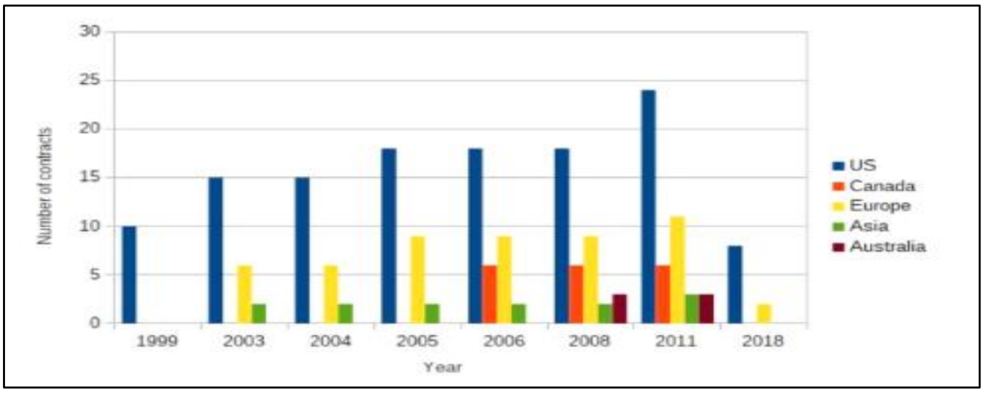
Graph 11: Cities in the United States for which weather derivatives are based on in the CME by share of total trade.



Source: Sutton – Vermeulen, 2021, “Managing Climate Risk with CME Group Weather Futures and Options”, CME Website.

Moreover, in recent years the number of listed contracts (one for each cities) was much higher than today. As shown in Graph 12, the number of cities listed in the CME in 2011 was 47, where 24 of them only in the United States, but also between the first decade of the millennium the number of listed cities was still higher than today.

Graph 12: Number of cities for which weather derivatives are listed, by year and by continent.



Source: CME Website data consulted in 2018, cited in: Bressan, G.M., Romagnoli, S., (2021), "Climate risks and weather derivatives: A copula-based pricing model", Journal of financial stability, 2021.

III. THE PRICING OF WEATHER DERIVATIVES

In order to calculate the value of temperature-based weather derivatives we cannot use familiar models such as the Black – Scholes model, as this model presupposes the existence of an existing underlying, which is definitely not the case of weather derivatives. (Műller, Grandi, 2000)

We can distinguish between three models of valuation: the Historical Burn Analysis (HBA), the index modelling and the daily average temperature simulation.

3.1 Historical Burn Analysis (HBA)

The method of historical burn analysis evaluates the contract against historical data and takes the average of realized payoffs as the fair value estimate. The key assumption of this method is that the past always reflects the future on the average. This is the simplest in terms of implementation, but also the one which can cause the largest pricing errors. (Cao, Li, Wei, 2003).

Cao, Li and Wei (2003) applied this method to call options written on the three-month (January, February and March) cumulative HDDs for Atlanta, Chicago and New York in a 20 years' time period .

Image 2: Estimate values of Call Options between 1988 and 1998 in three US cities (Atlanta, Chicago, New York) based on the average of the HDD Call Option payoff with exercise prices for 1500 HDD (Atlanta), 3200 HDD (Chicago) and 2500 (New York).

	HDDs for Jan 1 - March 31			HDD Call Option Payoff			Years in	Estimate of Call Option Value		
Year	Atlanta	Chicago	New York	Atlanta	Chicago	New York	Average	Atlanta	Chicago	New York
1979	1778	3851	2841	278	651	341				
1980	1672	3474	2702	172	274	202				
1981	1698	3183	2708	198	0	208				
1982	1587	3760	2791	87	560	291				
1983	1749	3002	2443	249	0	0				
1984	1660	3424	2724	160	224	224				
1985	1723	3591	2567	223	391	67				
1986	1416	3208	2533	0	8	33				
1987	1602	2813	2504	102	0	4				
1988	1649	3417	2593	149	217	93	10	22.50	63.70	69.60
1989	1242	3150	2417	0	0	0	11	34.00	77.64	71.73
1990	1009	2627	2078	0	0	0	12	39.67	71.17	66.08
1991	1354	3066	2217	0	0	0	13	36.62	66.31	63.54
1992	1325	2862	2439	0	0	0	14	49.93	89.50	63.79
1993	1514	3277	2667	14	77	167	15	57.27	98.47	74.47
1994	1410	3524	2921	0	324	421	16	69.25	92.31	69.81
1995	1295	3096	2370	0	0	0	17	70.29	119.82	82.82
1996	1666	3410	2608	166	210	108	18	77.39	113.17	89.78
1997	1102	3226	2377	0	26	0	19	82.37	121.63	95.68
1998	1545	2637	2060	45	0	0	20	92.15	148.10	107.95
							Highest	92.15	148.10	107.95
							Lowest	22.50	63.70	63.54
							Highest / Lowest	4.10	2.32	1.70

Note: The HDD call is for the period of January 1 - March 31, 1999. The three columns next to the year column contain the actual realized HDDs for Atlanta, Chicago and New York. The following three columns contain the payoffs of the calls with exercise prices of 1,500, 3,200 and 2,500 respectively for Atlanta, Chicago and New York. The last three columns contain the call option estimates based on different lengths of the sample period. We count the number of years backwards from 1998. For example, a sample of 17 years covers the period of 1982 - 1998, a sample of 16 years covers the period of 1983 - 1998, and so on.

Source: Weather Derivatives: A New Class of Financial Instruments, Cao, Li, Wei, 2003.

As shown in Image 2, the first three column shows the cumulative number of HDDs between January and March for each city and for each year between 1979 and 1998. Then the next three columns show the payoff for each year and according to different strike levels given to each cities (1500 HDD for Atlanta, 3200 HDD for Chicago and 2500 HDD for New York). The last three columns of the exhibit show the option value estimates under different sample lengths. (Cao, Li, Wei, 2003).

By looking at the graph, we can notice a high variance between the payoffs depending on the number of past observations we use. In fact, 20 observations will give a payoff of 92.15, while this data is 82.37 when only 19 observations are available. When 10 observation are available, the average payoff is 22.50, a different of 300% respect to 20 observation. A solution to this issue might be to use a larger time series, which of course show more changes in temperature, but a derivative payoff depends on the future temperature behavior, which may be quite different from history. This is especially so if the maturity of the derivative security is short. (Cao, Li, Wei, 2003)

3.2 Index Modelling

In order to fix the issues given by the Historical Burn Analysis, we can another approach for pricing temperature derivatives in which we can estimate the distribution of the weather index directly through a stochastic process called Index Modelling.

According to Nelken (2000), in order to use the index modelling approach the following steps must be taken:

1. Collecting and refining the weather index data given by the time series.
2. Using a stochastic process to reproduce the trend of the index.
3. Simulate different future scenarios
4. Calculate the price of the derivative for each future scenario.
5. Calculate the average of the prices
6. Price actualization based on the date of the valuation.

It is possible to go even further by modelling temperature data through the daily modelling approach.

3.3 Daily Modelling

Daily average temperature (DAT) simulation involves modelling the temperature on a daily basis in order to derive the dynamics of the indices and price the associating temperature derivatives under some theory of asset pricing. Unlike index modelling and the HBA, the daily modelling makes a more complete use of temperature data, while other approaches account for the temperature indices which include refinement of temperature data and may lead to losing information. Secondly, daily modelling provides more accurate representation of all indices and their distributions. By daily modelling, the distribution of an index is derived from the distribution of temperature. More flexible and accurate distribution is then allowed compared to direct modelling of the index. Another advantage is that only one temperature model is required for all contracts on one location. This ensures necessary consistency in pricing different contracts on the same location, which will further suit the purpose of hedging. which requires a model for each temperature index, Daily Modelling only uses a single model for each temperature index. Although this model can certainly provide the best valuations by reducing errors it is also the most difficult to implement because it is the most precise and has the largest number of criteria. If the temperature model is not good enough, or a mistake occurs when implementing the model, we may end up with large error in pricing of the temperature derivatives. It is also worth mentioning that access to weather data can be costly and not always available. (Jewson, Brix, 2005)

3.4 The Gaussian pricing model

A very simple, and quite often sufficient, formula for pricing individual options can been derived for the case of a Gaussian distribution of the weather index.

For example, assuming that one knows the mean (average) and standard deviation of CDDs or HDDs in a location, it is simple to approximate the price of an option. The algebraic expression in the figure on the following page relates the price of an option to three factors:

1. The standard deviation of the distribution;
2. The distance of the strike from the mean value;
3. The number of dollars per degree day specified in the contract.

If we define a normalized strike in terms of the number of standard deviations of the strike away from the mean value, the cost of the option is easily calculated from the relationship below:

Consider an option over a period for which the standard deviation of CDDs is 100 CDDs, with a mean value of 1000 CDDs, and we define the strike for the option to be at 1080 (i.e., this is a CDD call), with a specification of $5000 per degree day. The strike is 0.8 standard deviations out from the mean. Using the equation above, we determine that the value on the vertical axis corresponds to 0.125. To obtain the expected value of the option, we simply compute the product:

Option Value (in USD) = $5000 x 0.125 x 100 = USD 62500

(Considine, 2004)

IV. APPLICATION OF WEATHER DERIVATIVES IN RISK MANAGEMENT

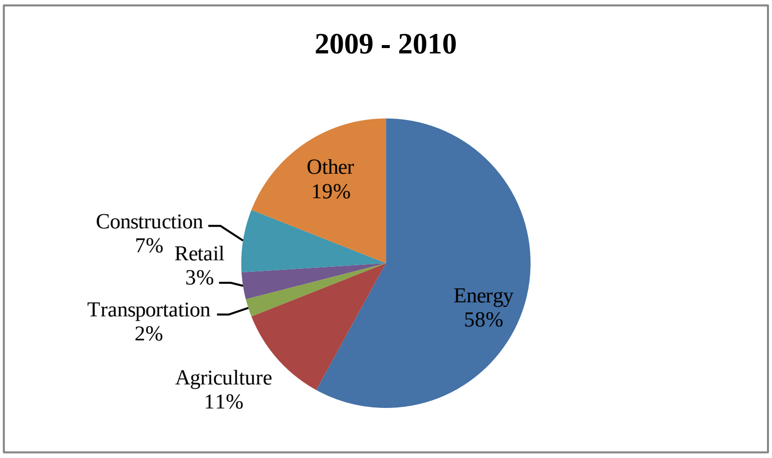
4.1 Weather derivatives and their use in each economic sector

The main purpose of weather derivatives, as well as any other risk management instrument, is to reduce the volatility of revenues and/or costs caused by volatility of the non-catastrophic weather. The purpose of indemnities paid by weather derivatives is to provide a cover for the lost revenues and excess costs caused by an adverse weather. Accordingly, weather derivatives can be considered effective if their application results in a lower volatility of the realized profits, thus decreasing the uncertainty i.e. the riskiness of future cash flows. (Stulec, Petljak, Bakovic, 2016).

According to the Chicago Mercantile Exchange, nearly 30% of the US Economy is directly affected by the climate, that is that climate can create significate changes in the company's revenues and costs. (CME Group Website)

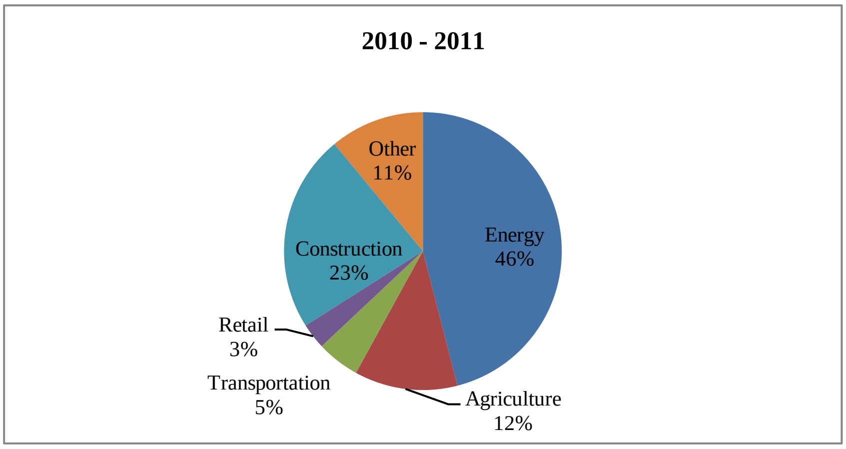
In 2011, the Pew Research Center Weather Risk Management Association, or WRMA, did a survey in order to quantify the use of weather derivatives for each economic sector. As shown in Graph 13, nearly half of this financial market is covered by the energy sector, but other than that, we can see that the rest of the market is far from being concentrated. Four other sectors, agriculture, retail, construction and transportation cover a quarter of the market share, while the remaining quarter is made up of sectors with a share of up to 4%.

Graph 13: Economic sectors by use of weather derivatives, as percentage of total use, in 2009 – 2010.



Source: PWC (2011): *Weather Risk Derivative Survey*. PWC, May, p. 14.

Graph 14: Economic sectors by use of Weather Derivatives, as percentage of total use, in 2010 - 2011.



Source: PWC (2011): Weather Risk Derivative Survey. PWC, May, p. 14.

Table 11 briefly describe the scenarios for which companies of each sector can hedge against by using weather derivatives, and the corresponding weather variable which impact the cost and revenues of the companies. When looking at the weather variable, it is possible to see that temperature is the main data influencing costs and revenues in most of the economic sectors, a fact which is noticeable also in the previous graph 1, which shows that temperature – related indexes such as HDD, CDD and CAT cover the largest share of all the concluded contracts both in the OTC market and in the CME.

Table 11: Economic sectors by use of weather derivatives, the weather variable and the scenario for which they can be used.

SECTORS	WEATHER VARIABLE	SCENARIO EXAMPLES
ENERGY (Gas and electricity distribution companies)	Temperature	Lower revenues due to mild summer or winter, which results in lower air conditioning and heating consumption respectively
AGRICULTURE	Temperature Rainfall	Lower output given by extreme summer or winter temperatures, or droughts or heavy rains.
CONSTRUCTION	Rainfall	Excessive rain can cause delays and leads

		to increasing costs
RETAIL SECTOR	Temperature Rainfall	Extreme temperatures may cause disruptions in revenues in many retail sectors. (Example, Restaurants, Theme parks).
SUMMER TOURISM	Temperature Rainfall	Lower reservations due to mild summer or heavy precipitations
WINTER TOURISM	Temperature Rainfall	Lower sales due to high temperature or insufficient snow packs

Source: Janda, K., Vylezik, T. (2011), "Financial Management of Weather Risk with Energy Derivatives," MPRA Paper 35037, University Library of Munich, Germany.

The following paragraphs are going to analyze the use of weather derivatives for two economic sectors: the energy sector and the agriculture sector, and describe a case study for each sector.

4.2 Weather derivatives in the energy sector

The energy sector is a category which includes all companies producing and distributing different source of energies, such as electricity and gas. In these contexts, climate affects both the production and the distribution of energy.

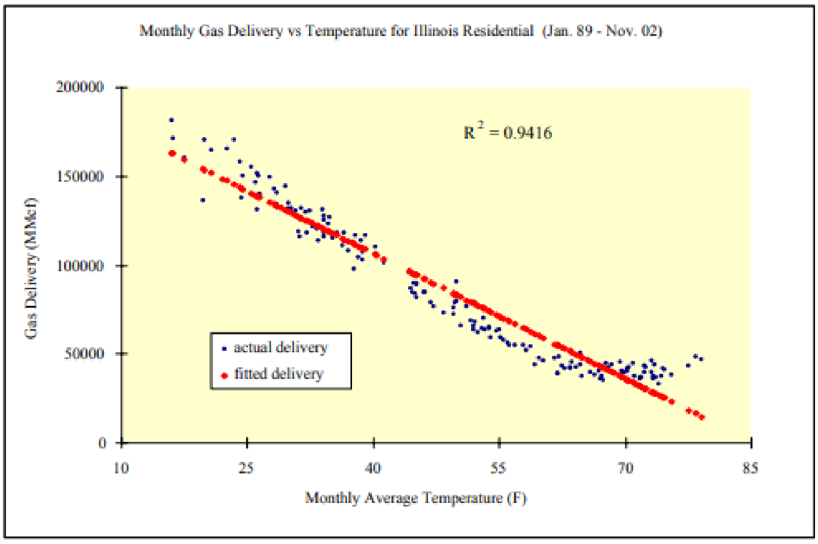
In the production of energy, climate plays a very important role in the production of renewable forms of energy. For example, a lower water level in a river where an hydroelectric plant is located will result in a lower electricity output. This is the example which convinced the Government of Uruguay to underwrite a weather derivative to protect the hydroelectric production located in the Rio de La Plata. Other more evident examples are to be found in wind and solar power, which are affected if the wind does not blows or the sun does not shine enough respectively.

When it comes to the distribution of energy, this is very evident first of all in the distribution of gas, but also in the distribution of electricity.

4.2.1. Gas distribution

The consumption of gas is almost totally directly correlated to the outside temperature, as shown in graph 15, which shows the correlation between the residential consumption of gas and the average temperature in the State of Illinois between January 1989 and November 2002. By looking at graph 15, it is possible to see almost a perfect correlation between this two data, with a coefficient of determination (R^2) very close to 1, at 0.94.

Graph 15: Linear regression between the average temperature in the Us State of Illinois (dependent variable) and the consumption of natural gas for residential use between 1989 and 2002.



Source: Cao M., Li A., Wei J., Weather derivatives: A New Class of Financial Instrument, op.cit., p.15.

Companies specialized in gas production and distribution can use weather derivatives to hedge against the risk of lower gas sales due to mild winters, as less gas is needed to heat buildings, but also against the risk that extremely cold temperatures can result in hikes in prices and disruptions of the gas distribution network, as explained in paragraph 4.2.1.1.

4.2.1.1 Example of a weather derivative as an hedge for the energy sector

In fall 2004, a put option was underwritten between an Italian company dealing with the distribution of natural gas, and XL Trading Partners, a financial company heart quartered in Bermuda. The operation was intermediated by an Italian bank, Banca Popolare di Sondrio, which managed to sign two different contracts, one with each of the two parties involved. Table 12 shows the most important features of the transaction between XL Trading Partners.

The whole contract signed between XL Trading Partners LTD and Banca Popolare di Sondrio be found in the Appendix A1.

Table 12: Main features of the weather derivative underwritten between the gas distribution company, XL Trading Partners LTD and Banca Popolare di Sondrio SPA.

MINIMUM MONTHLY AVERAGE TEMPERATURE PUT OPTION	
Type of contract	European Put Option
BUYER	Gas distribution company based in North – East Italy
SELLER	XL Trading Partners LTD
INTERMEDIATOR	Banca Popolare di Sondrio SPA
CONTRACT PERIOD	START: December 1st 2004; END: February 28th 2005 Saturdays and Sundays and the period between December 25th 2004 and January 6th 2005 included are not taken into account in the calculation of the index.
INDEX	Lowest Minimum Monthly Average Temperature (MMAT) between December MMAT, January MMAT and February MMAT. Second lowest between the previous three MMATs
WEATHER STATION	Treviso Sant'Angelo WMO 16099, ITALY
FALLBACK WEATHER STATION	Treviso Istrana WMO 16098, ITALY
PREMIUM PAID	Not specified due to privacy issues
MAXIMUM PAYOUT	1.050.000 Euros

Source: Contract of a weather transaction signed by XL Trading Partners, 2004.

The type of contract is a European Put Option with a duration of three months: from December 1st to February 28th.

The index used is the Minimum Monthly Average Temperature (MMAT).

To calculate this index, we first have to know the average daily temperature formula:

AVERAGE DAILY TEMPERATURE: (Daily Maximum + Daily Minimum) / 2

The MMAT is the lowest average daily temperature occurred each month. As in our example there are three months to consider, December, January and February, there will be December MMAT, January MMAT and February MMAT.

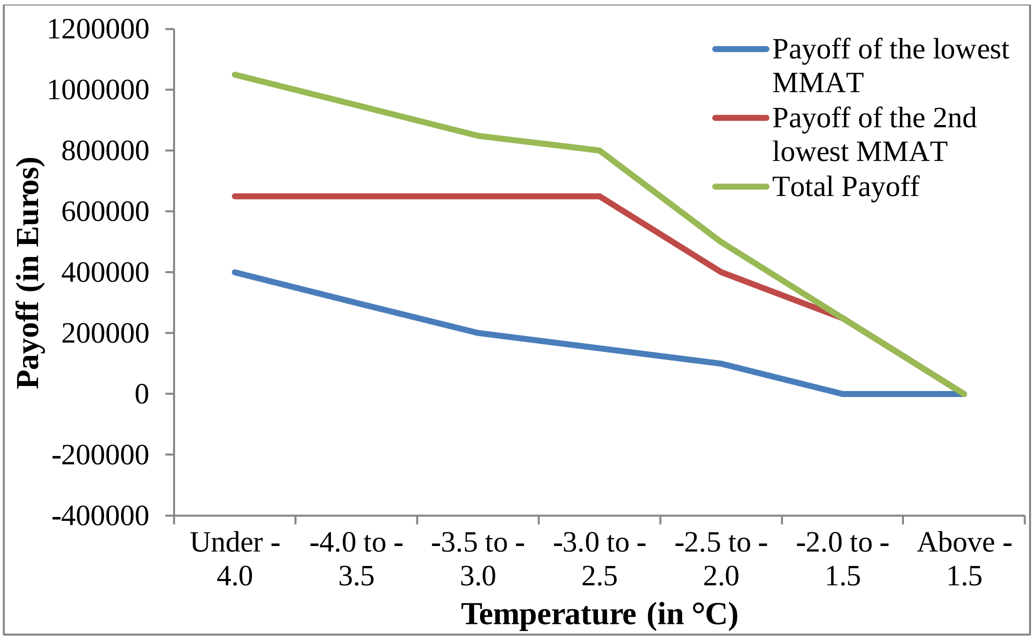
In the calculation of the MMAT every day is taken into account with the exceptions of Saturday and Sunday and the holiday period between December 25th and January 6th included. In total, the calculation regards 18 days in December, 17 in January and 20 in February. The Put Option takes into account two indexes, each of them will guarantee to the buyer a certain payoff: the lowest MMAT between the December MMAT, January MMAT and February MMAT and the second lowest MMAT.

Table 13: Payoff (in Euros) from the lowest MMAT, the second lowest MMAT and the total payoff, given as a sum of the previous two payoffs, by MMAT temperature range (in Celsius degrees).

MMTA TEMPERATURE RANGE (In °C)		PAYOFF (In Euros)		
From	To	Lowest MMAT	2nd lowest MMAT	TOTAL
Above 1.5	-1.5	0	0	0
-1.5	-2.0	0	250 000	250 000
-2.0	-2.5	100 000	400 000	500 000
-2.5	-3.0	150 000	650 000	800 000
-3.0	-3.5	200 000	650 000	850 000
-3.5	-4.0	300 000	650 000	950 000
-4.0	Under -4.0	400 000	650 000	1 050 000

Source: Contract of a weather transaction signed by XL Trading Partners, 2004.

Graph 16: Payoff the buyer will receive from the lowest MMAT, the second lowest MMAT and the total payoff, given as the sum of the two previous payoffs.

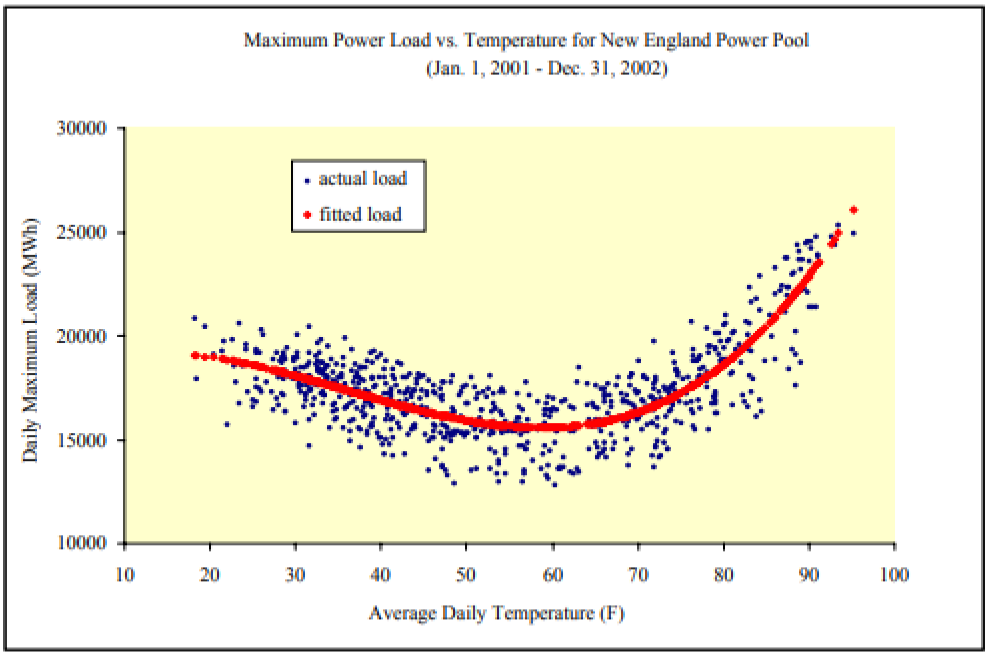


Source: Personal elaboration

4.2.2 Electricity distribution

In the consumption of electricity, the correlation with temperature is not as direct and linear as with the consumption of gas. By looking at graph 17, which shows the relationship between the maximum power load of electricity and the average daily temperature in the US region North England, it is possible to notice that this correlation is not linear, but it rather takes the form of a "U" shape, with the lowest point at around 60 °F (or 16 °C). This is because higher temperatures will result in an increase in the use of air conditioning and other systems of cooling. It is possible to notice a slight increase in electricity consumption when temperatures are lower than the average, even though this correlation is less relevant than the previous with higher temperatures. This is because electricity is used to light houses and to make furniture work, regardless of the outside temperature.

Graph 17: Linear regression between the average temperature in the US Region of New England and the daily maximum load of electricity in MWh:

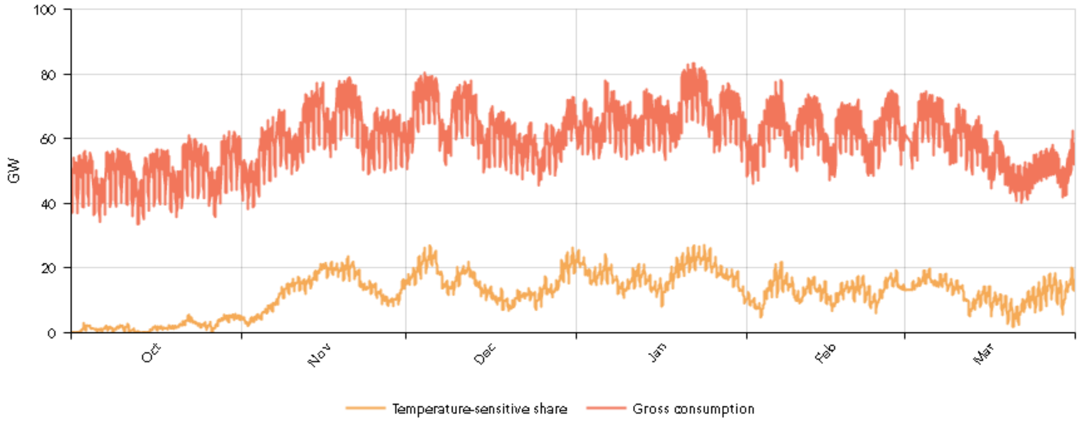


Source: CAO M., LI A., WEI J., Weather derivatives: A New Class of Financial Instrument, op. cit., p. 15.

As mentioned previously, energy consumption such as electricity and heating are partly influenced by temperatures. In fact, indexes such as HDD and CDD uses the temperature of 18°C (or 65°F) as a benchmark that shows the level at which energy consumption is at its lowest level. However, this relationship is not equal everywhere in the world, as energy is not used in the same share for heating and/or cooling in different areas of the world and because of the different average temperatures and people's adaptability to them in the different areas of the world.

According to the 2020 Electricity Report of RTE, France's Electricity Trasmission System Operator, in the winter between 2019 and 2020 french consumers consumed an average of 2.4 GW of additional electricity for each one degree drop in temperature. The report also shows that in December 2019 and in January 2020, around 30% of the electricity consumed depends on the temperature, while the remaining 70% is consumed regardless of the weather conditions, as shown in Graph 18.

Graph 18: Hourly electricity consumption in France from October 2019 to march 2020



Source: Consumption – Sensitivity to temperatures and end-uses : RTE Bilan électrique 2020 Website.

4.3 Weather derivatives in agriculture: The case of the Bonarda DOC Wine

Another sector in which weather derivatives find their application and effectiveness is agriculture. In fact, weather conditions can result in different crop yields, which affect not just market prices and final revenues, but also costs to maintain them. Zara (2008) studied the effectiveness of the use of weather derivatives in the wine industry, more precisely for the Bonarda DOC wine, a red wine produced in the Oltrepò Pavese, a hilly region 70 km south of Milan. The study took the data between 1998 and 2006. In his paper, he assumes that repercussion in costs, revenues, production and the quality of grapes occur both when temperature are not high enough and it rains too much, or when the temperature is too high and in case of droughts. For these reason, the wine producer has to hedge against both scenarios, and therefore decides to use a long straddle, meaning buying a call and put options with the same strike price, or a long strangle, in which the two strike prices are different. The strike price is the price (in this case the level of the index) in which the wine production is at his highest level. The index used in his paper is the GDD, for which the benchmark temperature is 10° C (or 18° F). So the formula to calculate the GDD of a day will be:

GROWING DEGREE DAYS (GDD): Average Temperature of the day – 10°C.

Zara (2010) cited the estimations of Fregoni (2005), who estimated that the weight of a Bonarda DOC bunch is the highest when the GDD index is around 1600. The paper states that the wine production reach its maximum if the cumulative value calculated between April 1st and October 31th, which is the typical wine reproductive cycle, is around 1600 GDD.

Table 14: Weight of a Bonarda DOC wine bunch by accumulated number of GDD collected between April and October.

GDD INDEX	BUNCH WEIGHT (in Kg)
1850	0.224
1800	0.241
1750	0.254
1700	0.264
1650	0.273
1600	0.287
1550	0.273
1500	0.264
1450	0.254
1400	0.241
1350	0.224

Source: Zara, C. (2008), I derivati climatici per il settore vitivinicolo, Centre for applied research in finance, Università Commerciale Luigi Bocconi, Working Paper No. 5/08

Considering a tick size per GDD of 6.50 Euro and the expected payoff given by the time series between 1998 and 2006, the price of the straddle equals 324.99 Euro, which comprises the cost of the purchase of one call option and one put option with a time duration of 6 months (from April to October).

So in order for the straddle to be convenient in hedging, the payout of one of the two options must be above 324.99, as shown in graph 5.

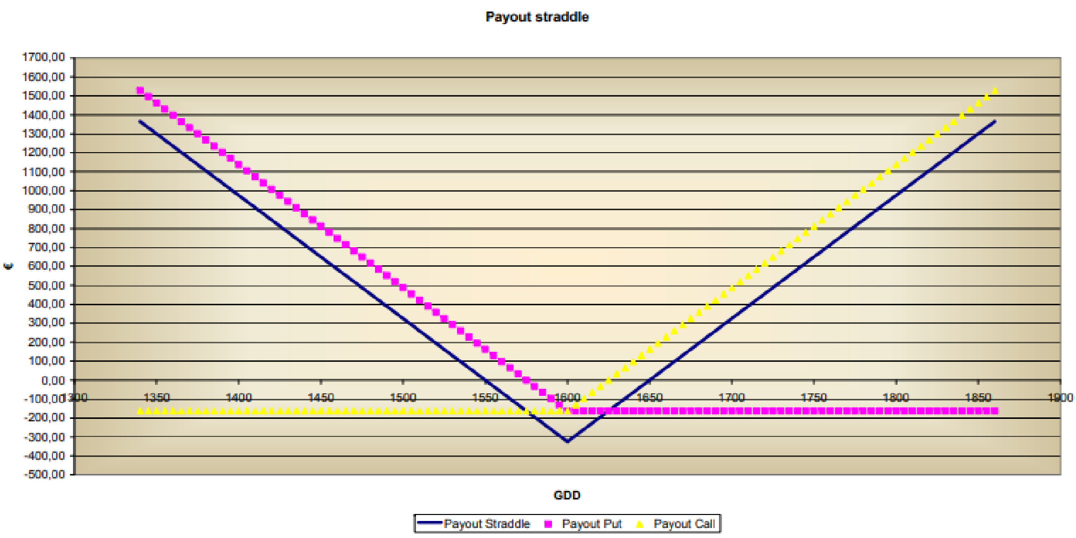
PAYOUT FORMULA OF THE STRADDLE

(Tick * (Strike – Index) – Premium Put) + (Tick * (Index – Strike) – Premium Call)

PAYOUT OF THE PUT

PAYOUT OF THE CALL

Graph 15: Payout functions of the put option (pink line), the call option (yellow line) and the straddle (blue line), which is the sum of the previous two, calculated using the payout formula of the weather straddle.



Source: Zara, C. (2008), *I derivati climatici per il settore vitivinicolo*, Centre for applied research in finance, Università Commerciale Luigi Bocconi, Working Paper No. 5/08

Table 15: Results of the model which shows the GDD Index (Indice STA), the Payoff of the straddle (A, in Euros), the profit or loss (Profitto/ perdita straddle), and the revenues with or without the hedging (Resa economica w/o copertura). (Data in Euros)

Anno	Superficie (ha)	Uve (q)	Resa media per ha	Indice STA	Payoff DD	Strike	Esercizio put	Esercizio call	(A) Payoff straddle (€)	Prezzi assicurabili (**)	(C) Differenza economica con P(€)	(A) Profitto/ perdita straddle (€)	Resa economica con copertura	Resa economica w/o copertura
1998	2.291,26	191.105,00	83,41	1.535	65	1.600	si	no	422,36	67,00	-653,90	97,36	5.685,57	5.588,21
1999	2.349,65	191.981,00	81,71	1.578	22	1.600	si	no	143,80	70,00	-630,22	-181,19	5.538,25	5.719,43
2000	2.326,11	200.310,45	86,11	1.596	4	1.600	si	no	25,60	65,42	-300,63	-299,39	5.334,18	5.633,57
2001	2.433,52	219.615,98	90,25	1.637	37	1.600	no	si	243,06	60,68	-177,16	-81,93	5.394,21	5.476,14
2002	2.227,05	221.779,00	99,58	1.515	85	1.600	si	no	551,19	65,89	398,33	226,20	6.787,80	6.561,60
2003	2.237,58	209.849,00	93,78	1.997	250	1.600	no	si	1.624,97	70,89	735,84	1.299,98	7.948,32	6.648,34
2004	2.851,70	229.405,00	80,44	1.492	108	1.600	si	no	699,39	71,33	-846,90	374,39	6.112,53	5.738,14
2005	2.947,33	262.617,00	89,10	1.507	93	1.600	si	no	601,89	65,50	-290,52	276,90	6.113,16	5.836,27
2006	3.103,33	287.331,00	92,59	1.724	124	1.600	no	si	802,74	55,83	-53,08	477,74	5.646,93	5.169,19
DEV.STD				150,03					446,21	4,73	481,18	446,21	792,61	457,47
CV				0,09					0,79	0,07	2,38	1,83	0,13	0,08
TTL											-1.818,23	2.190,05		
MEDIA													6.062,33	5.818,99

Source: Zara, C. (2008), I derivati climatici per il settore vitivinicolo, Centre for applied research in finance, Università Commerciale Luigi Bocconi, Working Paper No. 5/08

Table 15 shows that through a straddle the Put would have been exercised 6 times while the Call 3 times. In 6 out of 9 years, the straddle would have been profitable, realizing a payoff above 324.99 Euros, with year 2003 realizing the best profit of nearly 1300 Euros, a year which known in Italy for its extremely hot summer. In the other 3 years, the straddle would have proven unneeded, with 2000 as resulting the years with the biggest lost, because the index is the closest to 1600, the ideal value of the index. In these 9 years, the revenue with the hedging at 6062.33 Euros is almost 250 Euros higher than without hedging. (Zara, 2008).

Even if we remove the 2003 data which is definitely an outsider, the average payoff of the other 8 years with hedge, which equals 5.826,58 euros, is still above the average of the payoff with no hedge, which is 5.715,32 Euros, a difference of more than 100 Euros. (Zara, 2008)

4.4 The Hedge Ratio to develop an hedging strategy

In order for a company to construct a hedging strategy, it is necessary to quantify the relationship between economic outcomes (such as sales revenues) and weather conditions (as implied in weather futures prices). Sutton – Vermeulen (2021) developed a formula he called *Hedge Ratio* that balances the anticipated change in revenues (denoted as Δ Revenues) with the changing value of the subject derivatives contracts (Δ Value of Futures). A statistical regression between revenues and weather conditions is frequently useful in assessing these quantitative relationships.

HEDGE RATIO: Δ Revenues / Δ Value of Futures

Sutton – Vermeulen (2021) provides an example of an electricity distribution company using weather derivatives traded in the CME, but this formula can be applied to every economic sector and for OTC contracts. For example, ABC Utility Co. sells electricity in the Chicago area at $0.08/Kilowatt hour. Under normal winter weather conditions, ABC may forecast sales of 1 billion Kilowatt-hours (kWh) with a projected revenue of $80 million. However, ABC is concerned about the possibility of El Niño weather effects and would like to utilize HDD futures traded in the CME to hedge against the possibility of warmer than expected winter conditions. Assume that, based on historical regressions, ABC finds that its sales are positively correlated with the CME Group Chicago HDD Index with a sensitivity ratio of 0.80. I.e., a 1 percent change in HDD may give drive a 0.8 percent change in ABC's anticipated $80 million in revenues. Assuming futures are trading at 1,250.00, an effective hedge ratio may be calculated as follows. (Sutton – Vermeulen, 2021)

HEDGE RATIO OF ABC:

($80,000,000 x 0.8%) ÷ (1,250 x $20 x 1%) = 2,560 futures contracts

This suggests that ABC might sell 2,560 futures to hedge the risks of higher than expected temperatures and lower than expected revenues. Assume that temperatures are mild and that the HDD Index settles at 1,150. This decline of 100 HDDs (8 percent of original value of 1,250) implies that sales may decline from one billion to 936 million kWh for sales of $74,880,000 ($0.08/kWh x 936,000,000 kWh). This implies a revenue shortfall of $5.12 million. But this shortfall is offset by a corresponding $5.12 million profit in futures.

4.5 Weather derivatives or weather insurance

As a financial tool to manage risk, it is possible to draw an analogy between weather derivatives and another long – established financial tool: the insurance. However, some differences that prove that these two instruments are not perfect substitute of one another, as weather derivatives can solve issues which insurance cannot do.

One of the main difference between these two instruments regards the type of events covered by each: while insurance covers events with causes large disruption but with little probability that they might happen, weather derivatives, on the other hand, covers holders from weather fluctuations and anomalies which are much more commons and lead to remarkable consequences depending on the economic sector, such as decreasing demand or increasing prices due to lower output. (Hussain, 2022).

For example, a weather insurance might be helpful to a wine producer seeking protection from hail, but this product won't help him or her from lower output due to heavy thunderstorm or lower than average summer temperatures. In this case, selling a CDD future or buying a CDD Put Option would be the best solution.

Moreover, as the payoff of weather derivatives is based on a given weather index, it is also possible that the holder can receive the payoff even if the event for which the holder would like to hedge against does not cause any loss at all, which is very different from insurances, for which the insured always need to prove a loss. (Hussain, 2022).

Table 16 recaps the main differences between these two hedging tools.

Table 16: Differences between weather insurance and weather derivatives with examples.

	INSURANCE	DERIVATIVE
Loss demonstration required to receive the payoff	YES. The payoff is limited to the demonstrated loss.	NO, because they are index based, so the payoff is calculated regardless of the eventual losses
Types of event covered	Catastrophic events with low probability (es. Fire, flooding).	Non catastrophic events with high probability (Droughts, small snowpack on mountains, warmer than average winter),
Loss adjustment	YES	NO

Source: Hussain, A. (2022), *Weather Derivative: Definition, How It Works, Types & Examples,* Investopedia, 20/05/2022.

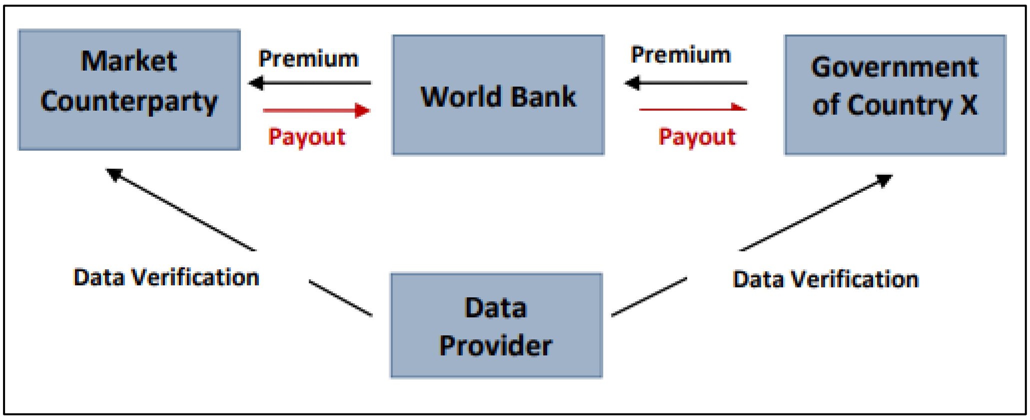
4.6 Weather derivatives as a financial aid for developing countries. The case of the World Bank

By looking at the previous graph 13 and graph 14 of the paragraph 4.1, which show the sectors in which weather derivatives are most used we can find out that, even if weather conditions affect all economies around the world, they particularly affect low and middle income countries, in which a larger share of their GDP comes from agriculture and energy production than first world countries, in which services make up the largest part of their income.

Taking into account agriculture, according to the World Bank Database, in 2021 agriculture counted for nearly one – tenth (9.1%) of the total GDP of what the UN labels as "Low & Middle Income Countries", while the same percentage for OECD members was only 1.4%. (Data Bank World Bank Website, 2023)

Therefore, on June 24th 2008 the World Bank announced its intention to use, along with the other types of aid the organization already provides, weather derivatives as a tool to help developing countries dealing with weather risks, especially flooding and droughts, In this type of aid, as shown in graph 16, the World Bank acts as an intermediator between the Government of the country in need and the market. The World Bank asks the Government to transfer part of its risk through the payment of a premium, and then uses the money to enter the market to stipulate a derivative contract with a counterpart. (World Bank, 2008)

Graph 16: Parts involved in a weather derivative contract intermediated by the World Bank and the relationships occurring between them.



Source: World Bank (2008), *Index based Weather Derivative*, available at https://thedocs.worldbank.org/en/doc/414271507314973952-0340022017/original/productnoteindexbasedweatherderivative2015.pdf

4.6.1 The Malawi case

The first country to be helped by the World Bank was Malawi, a landlocked country in southern Africa with a small economy heavily dependent on agriculture (38% of its GDP), and therefore, as seen in the first part of paragraph 4.6, very sensitive to weather events. In fact, the huge droughts occurring in 2005 brought severe hunger to the country and in order to fix this, the Government spent 200 million US dollars, a huge amount of money compared to the same year's GDP of 3.66 billion dollars. (Databank Worldbank Website, 2023)

To manage these issues, in 2008 the Government of Malawi turned to the World Bank and accepted to transfer a portion of its risk of severe drought to the international financial market using weather derivatives. If a severe and catastrophic drought had occurred, Malawi would have needed funds from the weather derivative within days, as the Government needed to access funds quickly in the event of a severe and catastrophic drought to reduce dependence on humanitarian appeals. For this transaction, the World Bank acted as an intermediary between Malawi and reinsurance companies or investment banks for the transaction. Malawi was required to pay a premium upfront, which was financed by the UK Department of International Development (DfID). The type of derivative purchased was a put option on a rainfall index. The index links rainfall and maize production, so that if precipitation falls below a certain level, the index will reflect the projected loss in maize production. The same operation was repeated for the years 2009 – 2010 and 2010-2011 between the months of October and March, which in Malawi corresponds to the maize growing maize season. Table 15 shows the main features of the 2009 – 2010 contract. The Government of Malawi would have received the payoff from the put option only if the maize index was 10% below the historical average, and that the maximum payout was 4.4 million dollars. (World Bank, 2012)

Table 15: Features of the Put Option regarding the production of maize underwrote by the Government of Malawi on behalf of the World Bank.

Dates	2009-2010
Type of Contract	Put option
Maximum Payout	US$ 4.4 million
Term	6 months
Trigger	10% below historical average maize index, which links rainfall and maize production
Index	Maize production

Source: World Bank (2012), *Weather Derivative in Malawi – Mitigating the Impact on Drought on Food* Security, Available at: https://documents1.worldbank.org/curated/en/549461468188946567/pdf/97466-BRI-Box391476B-PUBLIC-STUDY-Weather-Derivative-MalawiDerivative-Final.pdf

The weather derivative transactions in Malawi successfully tested the capacity of the Malawi Meteorological Services to transfer the rainfall data in real-time to international markets. Additional investment in the infrastructure of Malawi's Department of Climate Change and Meteorological Services will help improve the reliability of the index and the government's early warning system. (World Bank, 2012)

4.6.2 *The Uruguay case*

Uruguay is a south American nation which is classified, according to the World Bank, as an "High Income" country, making Uruguay, together with Chile, the only nation in the region classified with this label.

However, the Uruguayan economy is still highly dependent on economic sectors which are very affected by the weather. For example, According to 2023 data from the World Bank Database (2023), in 2015 the primary sector accounted for 6.3% of the total GDP, a much higher figure than the average of the countries the World Bank classifies as "High Income" at 1.3%, and even higher than the world average of 4.1%.

Moreover, electricity production in Uruguay is highly dependent of renewable forms of energy such as hydroelectric, solar, wind and geothermal. The World Bank Database (2023) showed that, in 2015, 88% of the electricity produced in Uruguay came from renewables, more than double the EU data of around 30% and far above the US data of just 13%.

As explained previously, renewable forms of energy exclusively depend on weather conditions. Wind energy production in fact cannot thrive when the wind is absent, and so does solar power when the sun does not shine. This assumption is also true for hydroelectric power, which depends on water to make the turbines rotate to produce electricity, and water levels in lakes and rivers have a direct impact on the electricity output. This is in fact the case for Uruguay, which satisfies more than half of its electricity needs from hydroelectric power. According to the Data taken from the World Bank Database (2023), when taking into account the 2015's 88% renewable energy share of the country previously mentioned, 60% comes from hydroelectric power while the remaining 28% from other forms if renewables.

The main player of electricity production in the country is UTE, which stands for Administración Nacional de Usinas y Trasmisiones Eléctricas, a state owned public electric company which acts as a monopoly in the production and distribution of electricity. When rainfall and/or accumulated water reserves is low, UTE is forced to purchase from abroad alternative fuels (mostly oil and natural gas) to use as inputs for electricity production. When the price of oil is high, generation costs become very expensive, affecting UTE's bottom line, and creating problems for both consumers and the national budget. In 2012, water shortages meant the company needed to purchase other sources of energy. That year the cost of supplying demand for electricity reached a record US$1.4 billion, far exceeding the company's original projections of $953 million. In order to cover the gap, UTE borrowed funds from the market, drew down the country's US$150 million Energy Stabilization Fund, and increased rates to consumers.

In order to tackle the risk, the Uruguayan government asked the World Bank for help, and together they agreed to underwrite a weather derivative. Graph 16 shows that the Government of Uruguay accepted to transfer part of its weather – related economic risks, such as low rainfall index and high oil prices to the World Bank in return for a premium paid in advance. As for the case of Malawi, the World Bank acted as an intermediate between the government and the market counterpart and accepted to pay to the Uruguayan Government, if the chosen index was lower than the agreed strike, a premium of up to 450 million US dollars, based on oil prices and the index.

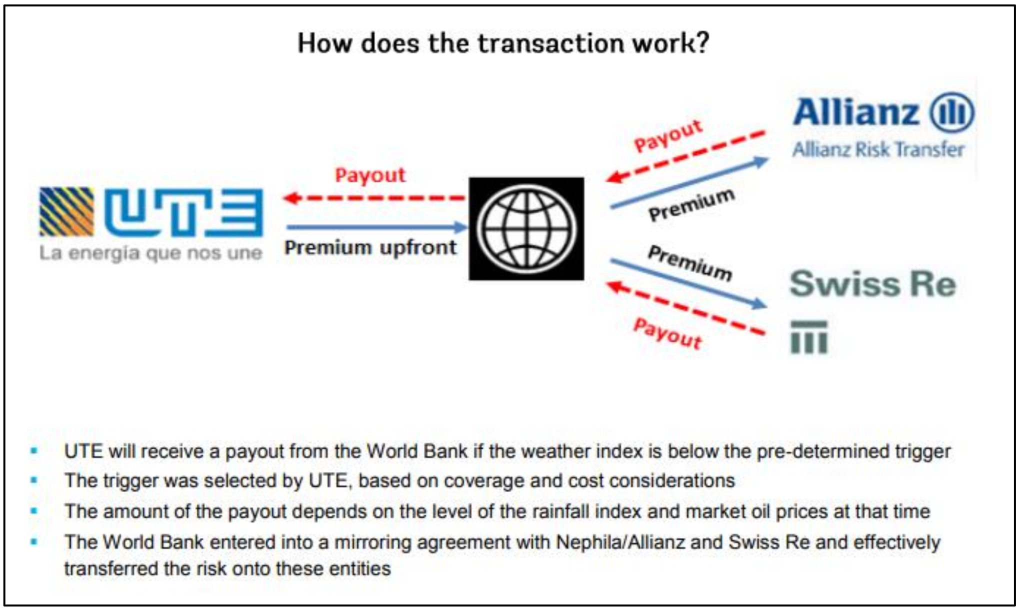
The index chosen was the Uruguay Potential Hydropower Energy Index ("UPHEI"), calculated by collecting and measuring the daily rainfall data at 39 weather stations spread throughout the two river basins of the Rio Negro and the Rio Uruguay, which UTE's hydropower is mainly dependent from. (World Bank, 2015)

Table 16: Features of the weather derivative bought by the World Bank on behalf of the Government of Uruguay.

Main Terms: 2014-2015 Uruguay Weather and Oil Price Insurance	
Type of Contract	Hydropower energy index-linked weather derivative
Maximum Payout	US$ 450 million (cumulative)
Term	18 months from Jan 1, 2014 to June 30, 2015
Weather Index	Uruguay Potential Hydropower Energy Index ("UPHEI")
Strike	Specified units of the UPHEI index
Settlement Dates	Semi-annual (for a total of 3 semesters)

Source: World Bank (2015), *Mitigating the impact of Drought on Energy Production in Uruguay*, available at:
https://documents1.worldbank.org/curated/en/510901468142790487/pdf/93908-Uruguay-Weather-Derivative-2015.pdf

Graph 16: Features of the transaction between UTE, the Uruguayan state – owned energy company, the World Bank and the two market counterparts, Allianz Risk Transfer and Swiss Re.



Source: World Bank (2015), *Mitigating the impact of Drought on Energy Production in Uruguay*, available at: https://documents1.worldbank.org/curated/en/510901468142790487/pdf/93908-Uruguay-Weather-Derivative-2015.pdf

The results of this program showed that the Index-based weather risk management cannot solve all of the challenges associated with a country's vulnerability to drought. It is a financial tool that can be integrated into a comprehensive risk management strategy.

4.7 What went wrong with Weather Derivatives

From their invention in the late years of the past millennium, weather derivatives saw a rapid and steady growth, which although did not last for long and as of 2023 the market remains very small in terms of volume and far from being established as other derivative markets such as commodities, foreign currencies and interest rates. The previous graph 10 and graph 12 analyzed in chapter 2 show that the market of weather derivative used to be promising in the first years from their invention, but then the market started declining.

Graph 10 of paragraph 2.6 showed that the size of the market reached its peak in 2005, with the total value of trades comprising OTC market and the CME standing at 45 billion US dollars, and then started declining and in 2011 the market size was only 11.8 billion US dollars, almost 4 times lower than the data registered 6 years before.

Moreover, the CME remains the only regulated market in which weather derivatives are traded, but they are very marginal financial instruments compared to other the market is known for, such as commodities. Graph 12 in paragraph 2.7 shows that the CME used to list weather derivatives for a much larger amount of cities. In 2011, hedgers could trade futures and options with indexes such as HDD, CDD and CAT for 47 cities all over the world. Twelve years later, in 2023, these figure is reduced by four folds to only 12 cities.

Even if the 2008 financial crisis can be easily blamed for Weather Derivatives unsuccessful experience, the main reasons for that are be found in their bad implementation and in the incorrect definition of the risk for which these instruments have been created, even though, as explained in the previous pages, they are in theory a valid instrument for hedging. What is wrong with weather derivatives and what is stopping them from being an established derivative market?

We will first analyze the drawbacks of weather derivative and then we will describe an example of wrong implementation of them.

4.7.1 Main drawbacks of weather derivatives

In order to explain what is stopping investors from dealing with weather derivatives, Till (2014) focuses on futures contracts, stating that a "commodity" such as the weather is not genetically suited for futures trading. In order for a future contract to be successful, it has to meet three criteria: level playing field, managing the risk of positions and the homogeneity of the commodity involved.

The level playing field criteria, which means that there must be a low symmetry of information between the parties involved, is met in the use of weather derivatives. (Till, 2014). The second criteria is not met, because if the risk of futures positions taken on by investors can be minimized by entering spread positions across related markets (Petzel, 2001), investors using weather derivatives combine each deal in a portfolio of uncorrelated risks.

Finally, homogeneity of commodity is also not met because the CME do not provide weather futures indexed to a large number of locations, meaning that investors can only have access to futures which usually do not hedge risk properly, because they are indexed to locations which are too far from their operations and might have different weather conditions. A solution to this issue might be to turn to the OTC market, which is by definition riskier than an exchange, to have access to futures indexed to a more specific location. (Till, 2015)

4.7.2 The case of Snowfall Weather Derivatives

From 2007 to 2011, the councils of some US cities underwrote weather derivatives contracts based on snowfall index. The purpose was to offset higher snow removal costs and higher fuel costs for the use of grittier vehicles. This type of derivative used to pay a fixed payoff if the accumulated snowfall index was higher than a predetermined strike level. These contracts used to be traded over the counter, but a portion of the market was also regulated. In 2006 in fact, the Chicago Mercantile Exchange began offering snowfall contracts on ten US location. In the first three years, the market expanded and in 2009 the CME launched contracts on four new locations, but in the following years, as the financial crisis was bringing out with many types of financial speculations, some issues with these financial products started to arise.

First of all, the main issue of snowfall weather derivatives was that the features of these products were based on data collected over the past 30 years, but over the years climate change has been proving not just that weather conditions change at a faster pace than ever before, and that over the last 10 years, snowfall had been declining steadily. In the case of the weather derivatives used to hedge against excessive snowfall levels, this meant that the possibility for the holders of overcoming the strike, and therefore to receive the payoff, was becoming even more remote. (Borzi, 2020)

Jeff Hodgson (2014), former head of the Chicago Weather Exchange (CWE), took the example of a contract which cost 30000 USD bought in November 2013 which expired in march 2014 that would paid out 100000 USD if the accumulated snowfall was 50 inches (or 127 centimeters). In January 2014, Hodgson stated that the total amount of snowfall since November 2013 was only 14 inches, very far from the 50 inches strike needed.

Moreover, according to NOAA (2023), the average yearly accumulated snowfall from 1991 to 2020 was just 29.8 inches, a very low data that discourages using this products. (Climate of New York City, Wikipedia)

A solution for this problem might be buying contracts with a lower strike, but this will mean being willing to pay an higher premium. This is exactly what happened.

In fact, snowfall weather derivatives had started being sold also for the opposite reason, that was to compensate the lack of snowfall which caused repercussion on revenues. In this case, the payout occurred if the index level was below the strike. Companies interested in this type of hedging were ski resorts, which revenues are closely linked to the amount of snowfall.

Also in this case, low snowfall levels were the reason that discouraged the involvement of the companies for these instruments. At first, holders of these instruments were benefiting from the hedging because the snowfall was under the predetermined strike but then, as the likelihood of low snowfall levels began to increase, companies who use to sell these products, such as insurance companies, started asking for higher premiums, which eventually discouraged investors from using these financial instruments. In the winter between 1999 and 2000, the company owning the ski resort in Vail, a mountain village in the US state of Colorado, underwrote an insurance against low snowfall levels and, at the end of the season, received a payoff of 13.9 million USD. From that year, insurance companies started asking for higher premiums, which made ski resorts to step back and decide not to seek for insurance.

Moreover, ski resorts were not very interested in this type of products because they were and still are used to pre – sell tickets for the entire winter season, making the need to hedge against low snowfall levels useless. In 2017, Vail Resorts, a company owning a large number of ski resorts in Colorado, stated that it did not use weather derivatives to mitigate losses due to low snowfall levels.

Another issue regarding weather derivatives is the transparency with which weather data are collected. An example of this regarded Mountain Creek Resort, a New Jersey ski resort, and the insurance company Everest Indemnity Insurance. In 2012, the ski resort sued the insurance company for a sum of 1.7 million USD. The two parties signed a contract stating that the ski resort company would have received the payoff if the number of days with an average temperature above 0 Celsius degrees was above the strike. The ski resort stated that the limit was overcome, while the insurance company contested the system with which the data on temperature had been collected. In 2017 the ski resort failed and was taken over in 2018 by a new owner.

In 2005, the Chicago Mercantile Exchange decided to withdraw all its snowfall related contracts, because of lack of interest from the investors. In 2013 in fact, not a single transaction was registered in the CME, while in 2011 the figure was 510. (Borzi, 2020)

CONCLUSION

We can say that life is much easier now than it was in the past, as we are living in an era in which the amount of needs people can satisfy is higher than ever, and in which there are an enormous amount of solutions to an enormous amount of problems. From education to health, but most importantly safety and financial resources.

Through this thesis we analyzed that the purpose of finance is not just to manage money and create more money, but also to hedge risks which usually are not under our own control, such as the weather.

Over the history, this purpose has always been carried out by insurances, but this thesis explained in the paragraph 4.5 that another more targeted and efficient alternative to them exists, and this are the use of Weather Derivatives. They in fact can protect from more frequent and less disastrous meteorological events, which in every case impact a company's revenues and costs.

Moreover, we analyzed in the paragraph 4.3 that even though hedging always comes with the inclusion of some additional costs, and that might lower resources on the short – term, their main goal is to stabilize revenues, making easier for companies to manage finances and plan on the long – term.

The only question about these products regard the market and their regulations. This has historically been one of the biggest drawbacks of all types of derivative, but in the case of weather derivatives is even higher, as the market remains very small in terms of volumes and contracts traded, and currently the only regulated market which list weather derivatives is the Chicago Mercantile Exchange.

However, even though weather derivatives is a term unknown to many, especially for people not expert in finance, and for people and companies which deal with finance every day, just a tiny piece of the enormous financial world, they can easily be conceived as a way to tackle a well-known problem which does affect us every day, climate change.

APPENDIX

A1. Weather contract signed between XL Trading Partners LTD and Banca Popolare di Sondrio SPA.

Contract #[redacted]

XL Trading Partners Ltd
1 Bermudiana Road
Hamilton
Bermuda HM 11

[redacted]

Address: [redacted]

Attention: [redacted]

Telephone No: [redacted]
Fax No:

Re: WEATHER TRANSACTION – Contract # [redacted]

Dear Sir or Madam:

The purpose of this document is to confirm the terms and conditions of the transaction entered into between Banca Popolare di Sondrio ("Counterparty") and XL Trading Partners Ltd ("XLTP") on [redacted]/2004 ("the Transaction"). This document constitutes a "Confirmation" as referred to in the ISDA Master Agreement specified below.

The definitions and provisions contained in the 2000 ISDA Definitions (the "Definitions"), in each case as published by the International Swaps and Derivatives Association, Inc., are incorporated into this Confirmation. In the event of any inconsistency between the Definitions and this Confirmation, this Confirmation will govern.

This Confirmation evidences a complete binding agreement between you and us as to the terms of the Transaction to which this Confirmation relates. In addition, you and we agree to use all reasonable efforts promptly to negotiate, execute and deliver an agreement in the form of the ISDA Master Agreement (Multicurrency-Cross Border) (the "ISDA Form"), with such modifications as you and we will in good faith agree. Upon the execution by you and us of such an agreement, this Confirmation will supplement, form a part of, and be subject to that agreement. All provisions contained or incorporated by reference in that agreement upon its execution will govern this Confirmation except as expressly modified below. Until we execute and deliver that agreement, this Confirmation, together with all other documents referring to the ISDA Form (each a "Confirmation") confirming transactions (each a "Transaction") entered into between us (notwithstanding anything to the contrary in a Confirmation), shall supplement, form a part of, and be subject to an agreement in the form of the ISDA Form as if we had executed an agreement in such form (but without any Schedule) on the Trade Date of the first such Transaction between us. Unless and until agreed otherwise by the parties, such ISDA Form shall be modified as follows: (i) it shall be governed by and construed in accordance with New York law; (ii) it shall have a Termination Currency of EURO; (iii) the Credit Event Upon Merger provisions will be applicable to both parties; (iv) the Automatic Early Termination provisions shall not apply; (v) the parties will be deemed to have selected Second Method and Loss as the calculation method in Section 6(e) of the ISDA Form; and (vi) subparagraph (ii) of Subsection 2(c) of the ISDA Form shall not apply. In the event of any inconsistency between the provisions of that agreement and this Confirmation, this Confirmation will prevail for the purpose of this Transaction.

Contract #[redacted]

Terms of Transaction. The terms of the particular Transaction to which this Confirmation relates are as follows:

Transaction Type:	Digital Lookback Monthly Minimum Average Temperature Put Option
Trade Date:	[redacted] 2004
Effective Date:	1 December 2004
Termination Date:	28 February 2005
Total Premium:	€ [redacted]
Total Premium Payment Details:	Counterparty shall pay XLTP five Business Days after the Trade Date.
Calculation Period:	1 December 2004 to 28 February 2005
Calculation Agent:	XLTP
Payment Dates:	Provided that a one time Payment Adjustment may be made after the Calculation Agent determines that an "adjustment" is payable in accordance with the Payment Adjustment below.
Payment Adjustment:	A one time adjustment will be made to the Payment Amount, for the Calculation Period, as determined by the Calculation Agent, if the IT-SMAMI (as defined hereunder) makes any correction or adjustment to the reported daily maximum and daily minimum temperatures within 120 days following the end of the last day within each Calculation Period, for any day within that Calculation Period.
Buyer of the Option: ("Fixed Amount Payer")	Counterparty
Seller of the Option: ("Floating Amount Payer")	XLTP
Average Temperature	The Average Temperature for each day is equal to the arithmetic average of the daily maximum and daily minimum temperature in degrees Celsius from and including 12:01AM on that day to and including 12:00 AM on the next day local time as measured and reported by the IT-SMAMI, for the Reference Weather Station. The daily maximum and minimum temperature measured and reported by the IT-SMAMI shall be rounded to two decimal places as follows: if the third number after the decimal point is five (5) or greater then the second number after the decimal point shall be increased by one (1), and if the third number after the decimal point is less than five (5) then the second number after the decimal point shall remain unchanged. The Average Temperature shall be rounded to two decimal places as follows: if the third number after the decimal point is five (5) or greater then the second number after the decimal point shall be increased by one (1), and if the third number after the decimal point is less than five (5) then the second number after the decimal point shall remain unchanged.

Contract # [redacted]

"IT-SMAMI" or "Servizio Meteorologico dell'Aeronautica Militare Italiana" means the Italian Meteorological Service, Italy's national meteorological authority (whose public website is www.meteoam.it), or its successor organization, which is responsible for observing, collecting and providing meteorological data for Italy.

December Index: The lowest Average Temperature of the December Calculation Periods.

December Calculation Periods shall be defined as:

Period	From and Including:	To and Including:
1	December 1, 2004	December 3, 2004
2	December 6, 2004	December 10, 2004
3	December 13, 2004	December 17, 2004
4	December 20, 2004	December 24, 2004

January Index: The lowest Average Temperature of the January Calculation Periods.

January Calculation Periods shall be defined as:

Period	From and Including	To and Including
1	January 7, 2005	January 7, 2005
2	January 10, 2005	January 14, 2005
3	January 17, 2005	January 21, 2005
4	January 24, 2005	January 28, 2005
5	January 31, 2005	January 31, 2005

February Index The lowest average temperature of the February calculation period.

February Calculation Period shall be defined as:

Period	From and Including	To and Including
1	February 1, 2005	February 4, 2005
2	February 7, 2005	February 11, 2005
3	February 14, 2005	February 18, 2005
4	February 21, 2005	February 25, 2005
5	February 28, 2005	February 28, 2005

Digital Floating Index Shall be the lowest of the December Index, January Index and February Index.

Digital Floating Index 2: Shall be the second lowest of the December Index, January Index and February Index.

Digital Amount: Shall be the applicable Digital Amount 1 that corresponds with Digital Floating Index 1 within the applicable Digital Strike Range 1.

Digital Strike Range 1 (Degrees Celsius)		Digital Amount 1
From	To greater than	(Euro's)
∞	-2.0	0
-2.0	-2.5	100,000
-2.5	-3.0	150,000
-3.0	-3.5	200,000
-3.5	-4.0	300,000
-4.0	-∞	400,000

Digital Amount 2: Shall be the applicable Digital Amount 2 that corresponds with Digital Floating Index 2 within the applicable Digital Strike Range 2.

Digital Strike Range 2 (Degrees Celsius)		Digital Amount 2
From	To greater than	(Euro's)
∞	-1.5	0
-1.5	-2.0	250,000
-2.0	-2.5	400,000
-2.5	-3.0	650,000
-3.0	-3.5	650,000
-3.5	-4.0	650,000
-4.0	-∞	650,000

Payment Amount: Notwithstanding any provision of the ISDA Form to the contrary, the Seller of the Option shall pay the Buyer of the Option an amount in EURO equal to the sum of (i) Digital Amount 1 and (ii) Digital Amount 2, which amount shall be due and payable on the applicable Payment Date, provided, however, that the maximum amount payable by the Floating Amount Payer shall not exceed €1,050,000.00.

Reference Weather Station(s) ("RWS"): Treviso San Angelo WMO 16099

Fallback Reference Weather Station ("FRWS"): Treviso Istrana WMO 16098

Fallback Methodology: If on any day during the Calculation Period official data for the RWS is unavailable the Fallback Methodology shall be employed. Amendment made to data as result of editing, quality control, changes in location,

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