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Weather derivatives: general overview, legal, tax, and application issues

Abstract

Weather derivatives are exchange traded (ETD) or over-the-counter (OTC) call to option or swap contracts that are triggered in the specified weather event. Nowadays, acute weather events lead to increasing popularity of such risk hedging instruments.

In this article the author presents a brief overview of the nature of weather derivatives, their applicability in various industries, available information on traded volumes, legal framework, taxation, pricing and basis risk, impact on financial resilience of investors.

Comparing to the US market, weather derivatives are still not so commonly used in the EU. On the other hand, the obligatory implementation of new EU corporate sustainability standards and the underling TCFD (Task Force on Climate-Related Financial Disclosures) methodology will definitely increase weather risk awareness at least among large and public listed companies. Therefore, the growth of the demand for weather risk transfer tools is expected.

In conclusion, next steps should be taken towards the improvement of the functioning of weather derivatives markets in response to the continuing trend of climate change.

Keywords: financial instruments, financial intermediaries, financial market regulation, securities law, security market regulation
JEL Classification: G23, G29, K220

Introduction

Catastrophic weather phenomena, as well as chronic climate change caused by global warming, have been a concern for mankind over the last decade. The IPCC latest report released by the Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [2022] mainly asserts about the negative impact of climate change on various aspects of human life in most parts of the world. Moreover, a lot of research notices a big part of economies affected by the weather. Nearly $ 1 trillion of the US economy is directly exposed to weather risk. It is estimated that this is nearly 30% of the US economy and 70% of the US companies [Alexandridis, 2013, p. 6].

How serious the problem is can be seen in the reports of many well-known organizations. For example, the Basel Committee on Banking Supervision released a report titled: *Climate-related risk drivers and their transmission channels* on how climate-related financial risks can arise and impact both banks and the banking system. The conclusion is that banks and the banking system are exposed to climate change through macro- and microeconomic transmission channels that arise from two distinct types of climate risk drivers. Firstly, they may suffer from the economic costs and financial losses resulting from the increasing severity and frequency of physical climate risk drivers. Secondly, as economies seek to reduce carbon dioxide emissions, which make up a vast majority of greenhouse gas (GHG) emissions, these efforts generate transition risk drivers [Basel Committee on Banking Supervision, 2021, p. 1]

Almost at the same time, in 2020, the U.S. Market Risk Advisory Committee of Commodity Futures Trading Commission released a report *Managing Climate Risk in the U.S. Financial System*. One of its messages is that climate change poses a major risk to the stability of the US financial system and to its ability to sustain the American economy. Climate change is already impacting or is anticipated to impact nearly every facet of the economy, including infrastructure, agriculture, residential and commercial property, as well as human health and labour productivity [Climate-Related Market Risk Subcommittee, 2020, p. 1]. A major concern for regulators is what we do not know. While understanding particular kinds of climate risk is advancing quickly, understanding how different types of climate risk could interact remains in an incipient stage. Physical and transition risks may well unfold in parallel, compounding the challenge [Climate-Related Market Risk Subcommittee, 2020, p. 1].

The International Swaps and Derivatives Association (ISDA) together with Ernst &Young released *Climate Risk Scenario Analysis for the Trading Book*; the report states that banks typically do not hold any derivatives specifically for the purpose of hedging climate and environmental risks. The ongoing development of sustainable finance products and sustainability-linked derivatives has the potential to provide additional active risk mitigation tools over time. In other words, the implementation of weather derivatives is expected to increase due to more concern to the environmental and social corporate sustainability in both financial and non-financial sectors.

Several attempts have been made in the scientific literature to identify and quantify the impact of investments in weather derivatives on the financial condition of enterprises. For example, Špička [2011] assessed the effectiveness of agricultural weather derivative in the conditions of the Czech Republic. An analysis of the correlation between barley and the weather was carried out. There was a statistically significant moderate relationship between barley yield and air temperature in April, May, June, and July. It was found that the main limitation of the use of weather derivatives in the Czech Republic is the heterogeneous production conditions that reduce the correlation between rainfall and yields at the regional level. Bakovic, Petijak, Štulec [2016] conducted research on a wider range of crops: grapes, corn, wheat, barley, soybean, and cotton. The authors came to a conclusion that weather derivatives are considered effective if their application results in a lower volatility of the economic value of the yield. The existing studies show that the weather derivatives effectiveness varies between the crops, geographical areas, and the covered time periods and are measured relatively by the volatility reduction ranges from 10.8% to 77.1% [Štulec, Bakovic, Petijak, 2016, p. 360].

Separate attention should be paid to the research of Perez-Gonzalez and Yun [2013], who did their research on energy companies in the US, as common traditional end users of weather derivatives. They tested the following two predictions:

1. The comparison results show that weather-exposed firms disproportionately increase in value after the introduction of weather derivatives. If weather derivatives drive this effect, then weather sensitive firms should be more likely to use weather derivatives after 1997.
2. The introduction of weather derivatives leads to an increase in company value. To the extent that left tail weather-driven cash flow realizations limit debt capacity or investments, the authors expected weather-exposed firms to increase in value as weather derivatives allowed them to insure against those negative weather realizations [Perez-Gonzalez,Yun, 2013, p. 24].

The authors came to the conclusion that hedging leads to a positive and significant effect on company value. Such a risk management allows firms to increase their debt capacity, invest more, and enjoy smoother earnings. Overall, the evidence is interpreted as supportive of the idea that financial derivatives have a positive effect on company value.

Due to the impact of climate change, the importance of implementing weather derivatives is growing. However, on the other hand, scientific research on this phenomenon is quite scarce and requires further development. For example, the number of publications for the last decade is not very high (up to 20). In particular, legal and tax issues are not discussed too much, the pricing methodology is not developed and there are no permanent statistical studies of the development of this specific market. Moreover, there is no scientific paper that would cover a 360-degree holistic view on the topic of weather derivatives.

The goal of the article is to make an introductory review of the essence of weather derivatives and to update legal, regulatory, and tax aspects as well as issues of basis risk and pricing of these financial instruments. In this research the author makes a brief introduction of the nature of weather derivatives, their applicability in various industries, available information on traded volumes, legal framework, taxation, pricing, and basis risk, their impact on financial resilience of investors.

In order to reach the aim mentioned above, the researcher used the following scientific methods: a review and analysis of the existing literature as well as an analysis of quantitative data from accessible reports.

Essence, history, and classification of weather derivatives

Weather derivatives are financial instruments that can be used by organizations or individuals as part of a risk management strategy to reduce risk associated with adverse weather conditions. Just as traditional claims whose payoffs depend upon the price of some asset fundamental, a weather derivative has an underlying measure such as a weather parameter, for example rainfall, temperature, humidity, snowfall, etc.

The European Market Infrastructure Regulation defines derivatives as financial contracts linked to the fluctuation in the price of an underlying asset or a basket of assets. Common examples of assets under which a derivative contract can be written are interest rates instruments, equities, or commodities.

The difference of weather derivatives from other derivatives is that the underlying asset in a weather derivative has no value and it cannot be stored or traded, while at the same time the weather should be quantified in order to be used in the weather derivative [Alexandridis, 2013, p. 1]. Hoornaert [2017] proposed the following comparison, presented in Table 1.

Table 1. Conventional vs weather derivatives

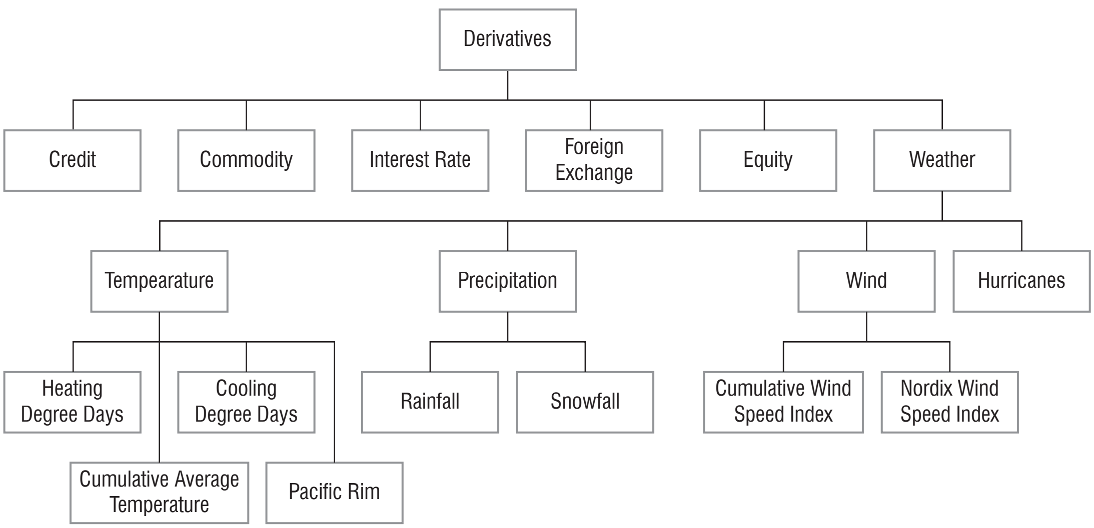
	Conventional Derivatives	*Weather Derivatives*
Risk Type	Price Risk	Volume Risk
The Underlying Asset	Commodity, Stock Index, Currency,…	Weather Index (e.g. temperature, rainfall, sunshine hours)
Physical Delivery or Cash Settlement	Both	Cash Settlement

Source: Hoornaert, 2017, p. 16.

As shown in Table 1, weather derivatives deal with volume risks. The risk is the effect of uncertainty on objectives. It can be positive, negative, or both, and can address, create, or result in opportunities and threats [International Organization for Standardization, 2018, p. 1]. The risk has its source. The risk source is an element which alone or in combination has the potential to give rise to risk [International Organization for Standardization, 2018, p. 1]. In operational risk management that covers the area of asset damages and supply chain disruptions, Chapelle [2019] specifies the following 4 groups of causes of risks: people, process, systems, external events [Chapelle, 2019, p. 49]. Therefore, the weather can be related to external events that lead to uncertainty in objectives. Hoornaert [2017] in his research mentions that weather variables impact such objectives as the price or the sales volume, as well as affect the company's financials from either the supply side, the demand side, or through operational exposures. Thus, payouts under the weather derivatives minimize the negative deviations of the above-mentioned parameters.

The first parties to issue weather derivatives in 1996 were energy companies, which, after the deregulation of energy markets, were exposed to weather risk. In September 1999, the Chicago Mercantile Exchange (CME) launched the first exchange-traded weather derivatives. The regulatory system offered by the CME helped the market to evolve. The CME eliminated the default risk. Moreover, the transparency of the transactions was increased since the prices of the contracts were public. [Alexandridis, 2013, p. 4]. In Figure 1 weather derivatives have been presented by Alexandris [2013] as part of a whole family of derivatives and can be classified according to the criteria of the base weather parameter.

Figure 1. Classification of financial derivatives



Source: Alexandridis, 2013, p. 5.

According to ISDA 2005 Commodity Derivative Definitions, generic forms of confirmation letters are presented for 3 types of weather derivatives:

- Weather Index Swap Transaction,
- Weather Index (Call Option/Cap),
- Weather Index (Put Option/Floor).

The weather derivatives market is organized as any other financial market. Hedgers (who buy derivatives to hedge weather risks) and speculators (who earn on just changes in price) are involved in transactions. Operations between hedgers and speculators take place in the primary market. In the secondary market, speculators trade between themselves. The main providers of weather derivatives are energy companies, banks, and insurance companies.

Weather derivatives have some similarities to property damage/business interruption insurance against catastrophic events and index-based insurance, as all of them mainly hedge the risk of disruptions in supply chain on both buyers' and sellers' side. Table 2 shows the comparison between these three weather risk transfer tools.

Table 2. Comparison between 3 types of financial instruments covering weather risks

Criteria	Property damage/business interruption insurance	Weather derivatives	Weather index (parametric) insurance
Frequency of covered events	Rare extreme weather events (e.g. hurricanes, floods). Temperature conditions are not covered	Can cover both low- and high-probability events, as well as high and low risk amount (e.g., mild or cold winters)	Can cover both low- and high-probability events, as well as high and low risk amount (e.g., mild or cold winters)
Loss compensation principle	The link with a real physical or financial loss is necessary	The holder can gain a profit. The link with a real physical or financial loss is not necessary	The link with a real physical or financial loss is necessary
Time and paperwork	Time consuming, requires a lot of paperwork and additional costs of loss adjustment	Immediate after weather data retrieval, less paperwork	Immediate after weather data retrieval, less paperwork
Property and damage inspection	Required	Not required, as based on objective criteria (e.g. index of the temperature)	Not required, as based on objective criteria (e.g. index of the temperature
Assignment of the indemnity rights	Not possible	Can be later sold to a third party	Not possible
Contractual risk	Exists in case of protracted debt or insolvency of the insurance company	Eliminated in case of exchange of traded derivatives	Exists in case of protracted debt or insolvency of the insurance company
Regulation in the EU	EU Insurance Distribution Directive Local law regulating the insurance market (IDD)	European Market Infrastructure Regulation (EMIR) and Markets in Financial Instruments Directive (MiFID)	EU Insurance Distribution Directive (IDD) Local law regulating the insurance market
Taxation in the EU	Insurance premium tax (IPT) which varies significantly in EU countries (0–32%)	General income taxation and financial transaction tax (FTT) in some EU countries	Insurance premium tax (IPT) which varies significantly in EU countries (0–32%)

Source: own work.

Among the differences presented in Table 2, the main one, related only to weather derivatives, should be distinguished, such as the loss compensation principle under which the holder can be compensated for even in the absence of a real loss (positive basis risk). Although the discrepancy between the calculated amount of indemnity and the actual loss is also present in weather index (parametric) insurance, the law in many countries still requires insurers to apply the principle of compensating for actual losses. In such a case, the insured must attach a so-called 'proof of loss letter' to the package of documents in the claim settlement process. Another alternative tools that can cover weather events are trade disruption insurance, catastrophic bonds, and industry loss warranties.

Today weather derivatives are being used for hedging purposes by companies and industries whose profits can be adversely affected by bad weather or for speculative purposes by hedge funds and others interested in earnings in those markets. Governments can also use weather derivatives at the local or national level, in order to avoid unexpected rises in their costs to cover consequences in their states caused by natural catastrophes. A good summary of the classification of weather derivatives in terms of their application in individual industries is presented by Alexandris [2013] in Table 3.

Table 3. Industries using weather derivatives

Hedger	Weather type	Risk
Agricultural industry	Temperature/precipitation	Significant crop losses due to extreme temperatures or rainfall
Air companies	Wind	Cancellation of flights during windy days
Airports	Frost days	Higher operational costs
Amusement parks	Temperature/precipitation	Fewer visitors during cold or rainy days
Beverage producers	Temperature	Lower sales during cool summers
Building material companies	Temperature/snowfall	Lower sales during severe winters (construction sites shut down)
Construction companies	Temperature/snowfall/rainfall	Delays in meeting schedules during periods of poor weather
Energy consumers	Temperature	Higher heating/cooling costs during cold winters and hot summers
Energy industry	Temperature	Lower sales during warm winters or cool summers
Hotels	Temperature/precipitation	Fewer visitors during rainy or cold periods
Hydroelectric power generation	Precipitation	Lower revenue during periods of drought
Municipal governments	Snowfall	Higher snow removal costs during winters with above-average snowfall
Road salt companies	Snowfall	Lower revenues during low snowfall winters
Ski resorts	Snowfall	Lower revenue during winters with below-average snowfall
Transportation	Wind/snowfall	Cancellation of ship services due to wind or buses due to blocked roads

Source: Alexandridis, 2013, p. 3.

As any other derivatives, weather derivatives can be divided into exchange traded and over-the counter derivatives. An exchange-traded derivative is a financial contract that is listed and traded on regulated stock or commodities exchanges. Exchange-traded derivatives have become increasingly popular because of their advantages comparing to over-the-counter (OTC) derivatives. These advantages include standardization, liquidity, and elimination of default risk. Unlike over-the-counter financial instruments, exchange-traded derivatives can be well-suited for some retail investors. In the OTC market, it is easy to get lost in the complexity of the instrument and the exact nature of what is being traded. The exchange has standardized terms and specifications for each derivative contract and acts as the counterparty for each exchange-traded derivative trade. It actually becomes the seller for every buyer, and the buyer for every seller. This eliminates the risk of the counterparty default in the derivative transaction.

An over-the-counter (OTC) derivative is one which is privately negotiated and not traded on an exchange. OTC derivatives account for almost 95% of the derivatives market. They have a significant impact on the real economy. When companies do not meet the requirements to be listed on a standard exchange, their securities can be offered as OTC, but may still be subject to some regulation by authorities. Over-the-counter (OTC) is a process executed via a broker-dealer network. The OTC market is generally deemed as risky, with less restrictive reporting requirements and lower transparency associated with these financial instruments. That is why after the financial crisis of 2008–2009 big attention is paid to OTC derivatives by financial supervisory authorities.

The comparison analysis between exchange traded (ETD) and OTC derivatives presented in Table 4.

Table 4. The differences between ETD and OTC derivatives

Exchange traded	Over-the-counter
Standard	Bespoke
Centrally cleared by stock exchange	Cleared by central counterparty clearing house (CCP)
More liquid	Less liquid
More transparent	Less transparent
Minimal contractual obligations risk	Higher contractual obligations risk
Automated	Phone based
Exchange hours	24/7
Set rules and procedures	Flexible
Limited products	Variety of solutions

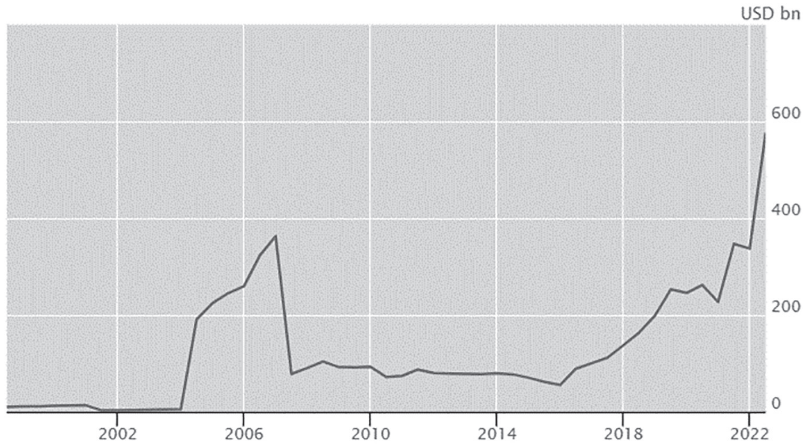
Source: own work.

Research on existing volumes of weather derivatives markets

Unfortunately, there is no centralized data source where one can get information on the traded volumes of weather derivatives in the world. The Weather Risk Management Association (WRMA) together with PWC conducted in the past annual surveys on OTC weather derivatives where main derivative companies participated (mainly big energy and international insurance companies). According to the latest report found, dating back to 2008 before the financial crisis, the total number of futures contracts and OTC derivatives traded in 2007–2008 amounted to 985,000, with a nominal value of USD 32 billion.

The Basel Committee on Banking Supervision [2018] collects statistics of ETD and OTC derivatives trading from 50 organized exchanges and OTC large dealers in 13 countries. Despite that, the main emphasis is put on statistics of foreign exchange and interest rate derivatives, there is also data on 'other derivatives', which includes inflation-indexed derivatives, volatility derivatives, dividend derivatives, weather derivatives, property derivatives, or freight derivatives as well as any derivatives with a nonstandard underlying asset which are developed for particular clients [Basel Committee on Banking Supervision, 2018, p. 3]. The dynamics of these 'other derivatives' are illustrated in Figure 2, which shows a significant increase in the popularity of these tools over the last 5–7 years.

Figure 2. The dynamics of notional value of other derivatives, as per classification of the Basel Committee on Banking Supervision



Source: www.bis.org/statistics

According to Till [2014], "most of the OTC weather derivatives business is provided by reinsurers. Swiss Re assumed a portion of the risk of the biggest-ever weather derivatives trade – a $ 500 million deal between the World Bank and Uruguay's Ministry of Finance that became effective January 1 – to hedge rainfall risk associated with the … country's hydropower generators" [Till, 2014, p. 1].

Another international organization, such as the World Federation of Exchanges, collects the data on ETD derivatives from 50 major exchanges, including the CME. However, WFE reports like BIS reports do not put weather derivatives into a separate directory.

A much better situation with statistics on weather derivatives is provided by the Chicago Mercantile Exchange. According to their report, in 2020, weather futures volumes increased by 60 percent year-to-date with a notional value of $ 750 million, while options volumes increased by 143 percent year-to-date with a notional value of $ 480 million. September 2020 marked the highest volume month in over two years, with an average daily volume (ADV) of over 1,000 contracts. As of December 2020, the open interest (OI) was over 29,000 contracts, a 175 percent increase year-over-year.[1]

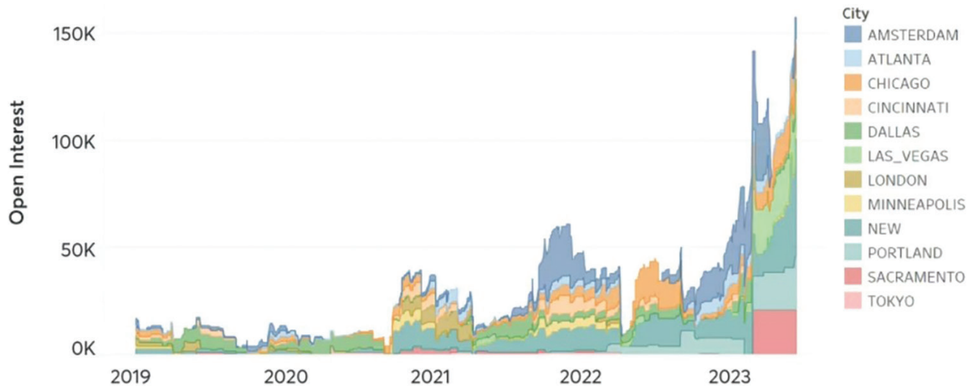
In 1999, the CME Group received approval from the CFTC to list the very first standardized weather futures contracts based on weather indexes of ten US cities. Subsequently, Amsterdam, London, and Tokyo, Japan, were added for an increased global coverage. Currently, there are nine US cities, two European cities, and one Japanese city listed at the CME Group. The volume statistics of CME derivatives are presented in Figure 3, which clearly shows the rapid increase in the open interest (number of contracts concluded) in 2022–2023.

Aydin [2019] in his research paper also mentions other organized exchanges in developed countries, which trade weather derivatives. Among them are the London International

[1] https://www.cmegroup.com/trading/weather/

Financial Futures and Options Exchange (Liffe), United States Future Exchange Market (USFE), European Energy Exchange (EEX).

Figure 3. CME Group weather futures and options open interest



Source: https://www.cmegroup.com/articles/2023/cme-group-weather-suite-expanded.html

Legal, regulatory, and taxations issues of the weather derivatives contract

The private OTC derivatives market comprises a kind of contracts based on ISDA standards. The International Swaps and Derivatives Association (ISDA) is a private trade organization whose members, mainly banks, transact in the OTC derivatives market. This association helps to improve the market for privately negotiated over-the-counter (OTC) derivatives by identifying and reducing risks in that market.

For nearly three decades, the industry has used the ISDA master agreement as a template for weather derivatives contracts, creating a basic structure and standardization. The weather derivatives contract comprises the following parts:

1. ISDA Master Agreement
2. Credit support annex (optional)
3. Long form confirmation
4. ISDA 2005 commodity derivative definitions sub-annex C
5. Weather appendix
6. Definitions appendix

The ISDA Master Agreement itself is a standard, but it is accompanied by a customized schedule and sometimes a credit support annex, both of which are signed by the two parties in a given transaction. The most significant advantages of the ISDA Master Agreement are improved transparency and higher liquidity. The ISDA Master Agreement stipulates whether the laws of the UK or New York state will apply. It also sets out the terms for valuing, closing out, and netting all operations in case of their termination.

A credit support annex (CSA) is a document that defines the terms for the provision of collateral (typically cash or securities) by the parties in a derivatives contract.

Long form confirmation is a kind of letter that confirms the execution of a weather derivatives contract based on ISDA standards and use the definitions recommended by Article XI of Sub-Annex C of the ISDA 2005 Commodity Derivative Definitions. The main definitions in weather derivatives contracts are as follows: transaction type, effective date, termination date, calculation period, premium, calculation agent, seller, buyer, notional amount, strike level, floating level, payment amount, limit, calculation date, payment date, data provider, data source, location, alternative data provider.

The ISDA 2005 commodity derivative definitions also stipulate recommended generic forms of confirmations for 3 types of weather derivatives: Weather Index Swap Transaction, Weather Index (Call Option/Cap), Weather Index (Put Option/Floor).

The weather appendix describes what precisely weather parameters and the weather index are used for. The definitions appendix modifies or supplements the standard definitions, recommended by the ISDA.

The regulation of weather derivatives is based on the general derivatives law, which is compiled in the European market infrastructure regulation (EMIR). The EMIR established common rules for central counterparties and trade repositories. The objective of the legislation is to reduce systemic counterparty and operational risk and help prevent future financial system collapses.

The following main EU Directives are implemented in this respect:

- Directive 2004/39/EC of 21 April 2004 on markets in financial instruments amending Council Directives 85/611/EEC and 93/6/EEC and Directive 2000/12/EC of the European Parliament and of the Council and repealing Council Directive 93/22/EEC;
- Commission Regulation (EC) No. 1287/2006 of 10 August 2006 implementing Directive 2004/39/EC of the European Parliament and of the Council as regards recordkeeping obligations for investment firms, transaction reporting, market transparency, admission of financial instruments to trading, and defined terms for the purposes of that Directive;
- Regulation (EU) No. 648/2012 of 4 July 2012 on OTC derivatives, central counterparties and trade repositories.

Regulation (EU) No. 648/2012 provides the following main definitions:

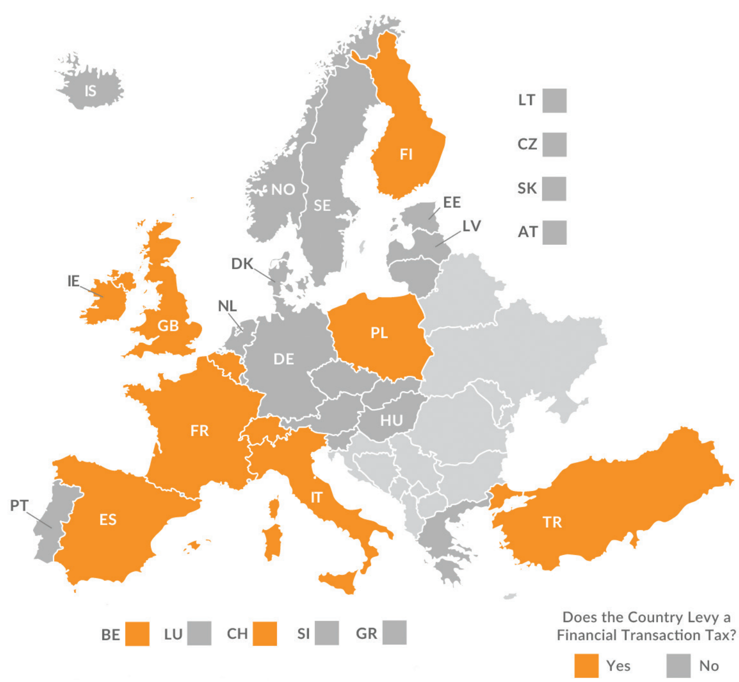
- Central Counterparty Clearing House (CCP) – a legal person that interposes itself between the counterparties to the contracts traded on one or more financial markets, becoming the buyer to every seller and the seller to every buyer;
- Trade repository – a legal person that centrally collects and maintains the records of derivatives;
- Clearing – the process of establishing positions, including the calculation of net obligations, and ensuring that financial instruments, cash, or both, are available to secure the exposures arising from those positions.

Article 37 of Regulation (EC) No. 1287/2006 states that regulated markets shall verify that the following conditions are satisfied:

(a) the terms of the contract establishing the financial instrument must be clear and unambiguous, and enable a correlation between the price of the financial instrument and the price or other value measure of the underlying security or asset;
(b) the price or other value measure of the underlying security or asset must be reliable and publicly available;
(c) sufficient information of a kind needed to value the derivative must be publicly available;
(d) the arrangements for determining the settlement price of the contract must be such that the price properly reflects the price or other value measure of the underlying security or asset;
(e) where the settlement of the derivative requires or provides for the possibility of the delivery of an underlying security or asset rather than cash settlement, there must be adequate arrangements to enable market participants to obtain relevant information about that underlying security or asset as well as adequate settlement and delivery procedures for the underlying security or asset.

The authorities which regulate both ETD and OTC derivatives markets are local supervisory bodies on financial institutions and financial markets as well as the European Securities and Markets Authority (ESMA).

Figure 4. Financial transaction taxes (FTTs) in Europe



Source: https://taxfoundation.org/financial-transaction-taxes-europe-2021/

The legal and academic literature on derivatives deals mainly with financial transaction taxes (FTTs), income and withholding taxes, and some VAT issues. Since the 2008 financial crisis, financial transaction taxes (FTTs) have been presented as a potential instrument to address financial market instabilities and as a source for tax revenue. Figure 4 shows the situation in Europe regarding the imposition of FTT by different countries.

As can be seen in Figure 4, governments of 8 EU countries implemented FTT, which is applied to selected financial instruments as percentage of the underlying asset's value, when it is traded. The variety of rates depends on the country and the type of underlying asset, as shown in Table 5.

Table 5. European OECD countries with a financial transaction tax (FTT), as of 2019 (in %)

Country	Tax Rate
Belgium (BE)	0.12–1.32
Finland (FI)	1.6–2.0
France (FR)	0.01–0.3
Ireland (IE)	1
Italy (IT)	0.02–0.20
Poland (PL)	1
Switzerland (CH)	0.15–0.30
United Kingdom (GB)	0.5–1.5

Source: https://taxfoundation.org/financial-transaction-taxes-europe-2021/

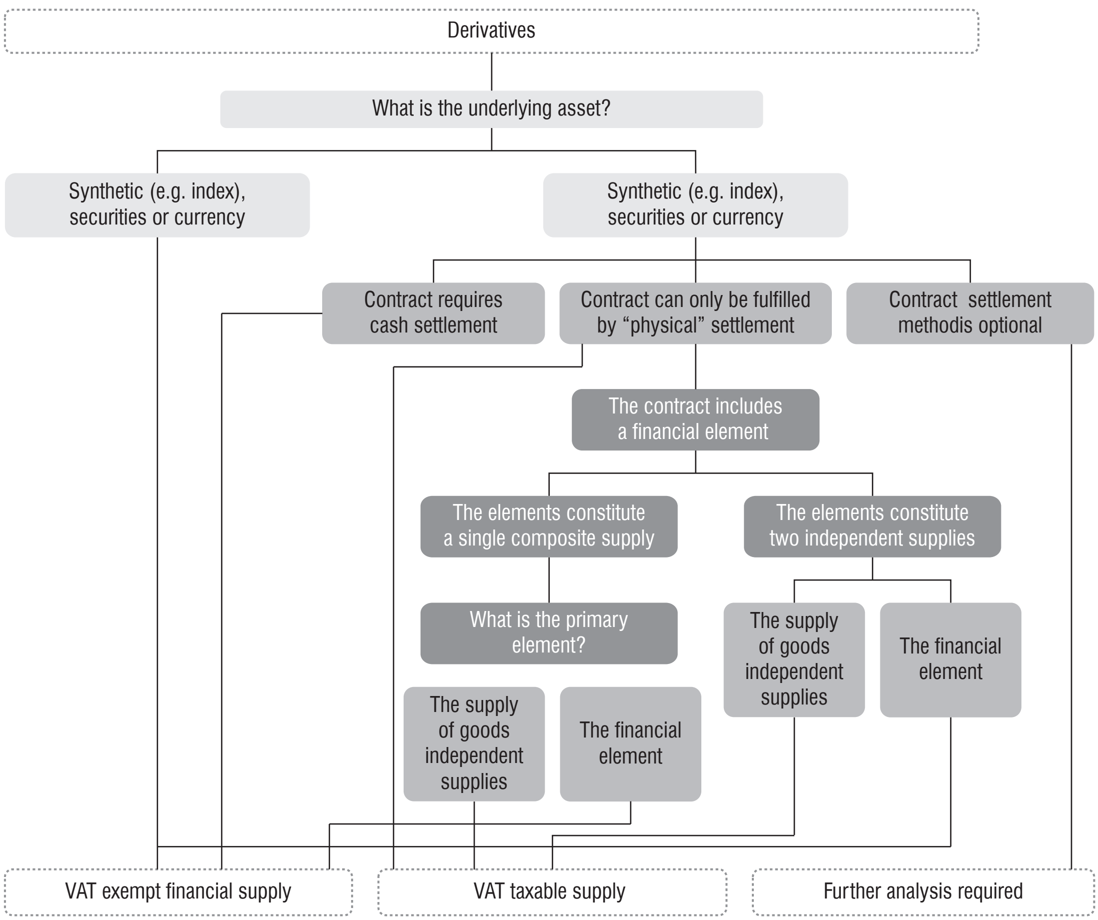
As for income taxation, there is no unified practice in EU countries. The Ministry of Finance of the Republic of Slovenia in their release regarding taxation in the country state that the tax on derivative instruments gains is payable by resident individuals and is levied on the difference between the value of the derivative instrument upon disposal and its acquisition value. It is levied at degressive rates depending on the period of holding (from 27.5% to 0%); 0% (tax exemption) is applied when a holding period is longer than 20 years. Gains realized from short-term contracts are taxed at 40% [Ministry of Finance. Republic of Slovenia, 2022, p. 6].

The Global Legal Group (GLG) on their leading global platform for legal reference ICLG.com has published the releases regarding legal and taxation issues on weather derivatives in 15 countries. For example, in Germany, while derivatives transactions may result in claims or liabilities (which can constitute assets/liabilities also for tax purposes), it is the income from derivatives transactions that is taxed as income, i.e. profits trigger income tax or corporate income tax and potentially trade tax, while losses are – subject to certain restrictions (e.g. ring-fencing) – generally deductible. Generally speaking, proceeds from derivatives transactions are subject to German withholding tax (at a rate of 25% plus a 5.5% solidarity surcharge thereon, i.e. at an aggregate rate of 26.375%). This is particularly the case where derivatives transactions are entered into by non-business individuals.

There are some issues in some countries regarding application of VAT tax in derivatives deals. For example, the Ernst & Young report mentioned criticism of the new Italian Tax Authorities position regarding new VAT application in the Repo (short-term agreement to sell securities in order to buy them back at a slightly higher price) to financial derivatives.

Hokkanen [2021] in her presentation *Derivatives and the European VAT System* stresses that there is no unified definition of derivatives in VAT regulations of EU countries. Interpretations may depend on legislature and its objectives. Moreover, the author provides differences between derivatives and sales contracts, where VAT are mainly applied, analyses VAT Directive (2006/112/EC), according to which the supply of goods and services are subject to VAT. Afterwards, the expert finds similarities from a legal point of view between derivatives and goods or services, insurance, securities, legal tender, and gambling, which leads to some uncertainty in application of VAT. Eventually, the author provides an overview of VAT treatment regarding derivatives in four Scandinavian countries and suggests using the scheme presented in the chart below (Figure 5).

Figure 5: VAT application decision scheme



Source: Hokkanen, 2021, p. 31.

Figure 5 reflects the complexity of tax issues in relation to derivatives and shows the risk of applying VAT in certain situations.

The problem of basis risk in weather derivatives

If the entity at time *t* would like to sell their real (physical) asset *S* at spot price *St* in a while, i.e. at the date of real transaction *T*, the preferred price S_t can be changed due to the impact of market conditions to spot price S_T. In such a case, the market risk can be defined as $|S_t – S_T|$. Herewith, the risk for the company can be negative (long exposure) if $S_T < S_t$. In order to convert such 'uncertainty' into 'certainty', the firm, by paying some premium at exchange or OTC markets, can buy futures or forwards contracts (short call option), i.e. to deliver the assets at price F_t that hedges the spot price of real (physical) asset *S* by the difference in futures prices of the 'underlying' asset $|F_t – F_T|$, specified in this futures contract. Wherein, the difference between the spot price of the real (physical) asset S_j and futures price of the underlying asset in the futures contracts F_j at any time j = 0, 1… t…T is called 'basis' (b):

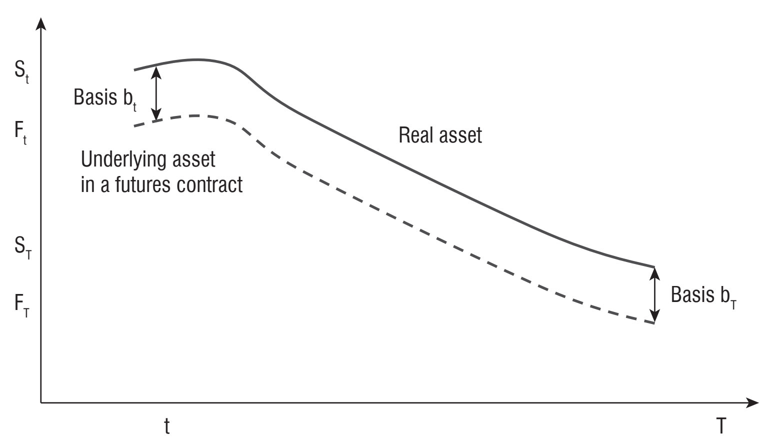
$$b = S_j – F_j \text{ for any time } j = 0, 1\ldots t\ldots T$$

In the prefect world, the futures price of the underlying asset fully correlates with the spot price of the real (physical) asset (correlation coefficient = 1). It follows from the example above that the final price that the company will gain from selling the real (physical) asset (if the futures contract is also executed) will make:

$$S_T + (F_t – F_T) = Ft + (S_T – F_T) = F_t + b$$

If *S* and *F* fully correlate it means that the basis value is constant (Figure 6), hence $F_t + b = S_t$.

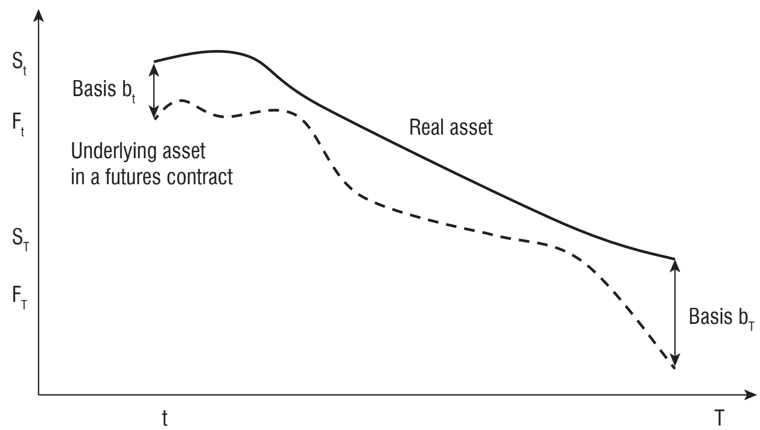
Figure 6. Constant basis risk scenario



Source: own work.

However, in the real world the basis can change over time (in our example from t to T). The measurable uncertainty in the value of the basis is called 'basis risk'. For the seller of real assets (long exposure, i.e. their price will go down), if $b_T < b_t$ (unexpected basis weakening) it means the loss and vice versa, gain, if $b_T > b_t$ (strengthening scenario as depicted in Figure 7).

Figure 7. Basis risk strengthening scenario



Source: own work.

For the buyer (short exposure, i.e. the price will go up) the position is opposite.

The success of index-linked catastrophic loss instruments strongly depends on basis risk, which can be described as the potential loss due to a low correlation between the insurer's losses and the index [Gatzert, Kellner, 2011, p. 143]. Basis risk arises as soon as an asset and the underlying asset of a derivative are not perfectly correlated [Blom, 2009, p. 15]. This imperfect correlation between the asset and the underlying asset of the derivative creates potential for excess gains or losses in a hedging strategy. Imperfect correlation reduces efficiency of the hedging instrument and increases risk of the total portfolio.

In the language of mathematics, basis risk is measured by means of the conditional probability β, which represents the probability that the industry index does not exceed its trigger, given that the real losses exceed a predefined critical loss level. Different weather indexes have different correlations with the value of the asset. For example, the temperature time series is much more uniform spatially and allows trading against well documented sites with less basis risk [Cui, 2014, p. 2].

The main reasons for the basis risk are listed in Table 6, resulting from the analysis of works of Adam-Müller and Nolte [2011], Barbi and Romagnoli [2018], Elabed, Bellemare, Carter, Guirkinger [2013], Yu, Vandeveer, Volesky, Harmoney [2019].

Table 6. The main reasons for the basis risk

No.	Reason	Example
1	Assets mismatch	The company is selling milling quality wheat, but in financial markets they can buy only futures of animal forage wheat
2	Time mismatch	Futures cannot be available at your desired delivery date, i.e. the company has to realize the futures contract before or after the delivery date of the real asset
3	Location (geographical) mismatch	The company is selling wheat to buyers, hence, has exposure in their national markets, but futures contracts are available only at foreign MATIF markets that use their own price indices.
4	Liquidity in financial markets	Due to liquidity constraints, it is not possible to buy or sell futures contracts in time
5	Errors in measurements	There is a direct formula between windspeed and energy production by renewables. However, OTC or exchange markets use data from weather stations, located at some distance from wind turbines and landscape and height peculiarities of the windfarm area are not taken into account

Source: own work.

Fundamentals of weather derivatives valuation methodology

Traditionally, financial contingent claims are priced by no-arbitrage arguments, such as Black-Scholes pricing model, based on the notion of continuous hedging [Bellini, 2005, p. 6]. However, the Black-Scholes methodology cannot be applied in the case of weather derivatives, simply because this model implies the existence of a negotiable underlying asset, or in other words derives the price of the derivative from the price of the actually existing underlying asset. This prerequisite is obviously not fulfilled in the case of weather derivatives. First of all, what does the weather cost? It must also be mentioned that this procedure does not give consideration to the seasonal nature of the weather, nor are the assumed log-normal distributions always reconcilable with data from historical observations.

In light of this, two approaches are used to calculate the price of weather derivatives: the burn analysis and the temperature-based models.

The burn analysis approach is very simple to implement and very easy to understand. It requires only a good source of weather data. The burn analysis asks and answers the question: "What would we have paid out if we had sold similar derivatives every year in the past?". The procedure included the following steps: collect the historical weather data; calculate the weather index; make some corrections to the data; calculate the resulting trade payoff for every year in the past; calculate the average of these payout amounts; discount back from the settlement date to today; add risk premium. The main limitation of this approach consists in not taking into account temperature forecasts. The burn analysis assumes that the next season implies the same weather trend as in the past, including frequency and severity of extreme events.

On the other hand, the temperature-based models focus on modelling and forecasting the underlying variable directly. Such models proceed as follows: collect the historical weather data; make some corrections to the data; choose a statistical model; simulate possible weather patterns in the future; calculate the index (HDD, CDD, etc.) and the contingent claim value for each simulated pattern; discount back to the settlement date. The temperature-based models improve the burn analysis approach by building a structure for daily temperature directly and not for degree day indexes. The simulations in step 4 are usually performed by using the Monte Carlo algorithm. The parameters of the model are generally estimated by the method of moments or maximum likelihood approach.

Cui [2014] proposed three different models for modelling the temperature and pricing the temperature derivatives. These three models are: (1) L´evy process driven Ornstein-Uhlenbeck model, (2) L’evy process driven continuous-time autoregressive model and (3) regime-switching models with Brownian motion and general L´evy process jumps. Instead of using the standard Brownian motion for the driving stochastic variables in these three models, more general L’evy family process is used to describe the randomness [Cui, 2014, p. 132].

Summary

The share of weather derivatives is quite miserable in the overall derivatives market at the moment. However, the importance of these tools is extremely growing due to the trend of global climate change. Comparing to the US market, weather derivatives are still not so commonly used in the EU. On the other hand, the obligatory implementation of the new EU corporate sustainability standard, and underling Task Force on Climate-Related Financial Disclosures (TCFD) methodology will definitely increase weather risk awareness at least of large and public listed companies. Therefore, the increase in the demand for weather risk transfer tools is expected.

Therefore, the requirements for these instruments will increase. This means, above all, improvements in the following areas:

- Change in BIS reporting guidelines, i.e. moving weather derivatives into a separate category for further representation of this market development in BIS reports.
- More research in elimination of basis risk, whereby developing new weather index models, especially for non-energy industries (e.g. the expected yield index for agriculture).
- Further development of climate data science in order to collect and process effectively the weather data, which in its turn should be publicly available and transparent for all market participants.
- Standardization and unification of legislation in the EU, regulating financial solvency of derivative providers, legal framework of derivative contracts, and taxation.
- Development of pricing methodology in order to reach a trade-off between participants in the weather derivatives market, hence sustainability and growth.
- Further scientific research in the field of weather derivatives, climate risk, and the impact of weather derivatives on the financial results of hedging companies.
- Popularization of weather derivatives in the economic society.

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