ΣΧΟΛΗ ΕΠΙΣΤΗΜΩΝ ΔΙΟΙΚΗΣΗΣ ΕΠΙΧΕΙΡΗΣΕΩΝ
ΤΜΗΜΑ ΛΟΓΙΣΤΙΚΗΣ ΚΑΙ ΧΡΗΜΑΤΟΟΙΚΟΝΟΜΙΚΗΣ
ΠΡΟΓΡΑΜΜΑ ΜΕΤΑΠΤΥΧΙΑΚΩΝ ΣΠΟΥΔΩΝ ΣΤΗ ΛΟΓΙΣΤΙΚΗ ΚΑΙ ΧΡΗΜΑΤΟΟΙΚΟΝΟΜΙΚΗ

Διπλωματική Εργασία

# WIND DERIVATIVES FOR MANAGING RISK IN THE WIND RENEWABLE ENERGY SECTOR

του

ΧΑΛΚΙΑ ΟΡΕΣΤΗ ΝΙΚΟΛΑΟΥ
Επιβλέπων Καθηγητής: Ζαπράνης Αχιλλέας

Υποβλήθηκε ως απαιτούμενο για την απόκτηση του Μεταπτυχιακού Διπλώματος στη Λογιστική και Χρηματοοικονομική

Οκτώβριος 2023

**Περίληψη**

Αυτή η διατριβή παρουσιάζει μια ολοκληρωμένη διερεύνηση των θεμελιωδών στοιχείων της αιολικής ενέργειας και την ενσωμάτωσή τους στη διαχείριση κινδύνων, εστιάζοντας στον κεντρικό ρόλο των αιολικών παραγώγων στον μετριασμό των κινδύνων που σχετίζονται με τον άνεμο. Ξεκινώντας με την αποσαφήνιση των θεμελιωδών αρχών της αιολικής ενέργειας, εμβαθύνουμε στον περίπλοκο κόσμο της διαχείρισης κινδύνων στον τομέα της αιολικής ενέργειας, αναγνωρίζοντας τις μοναδικές προκλήσεις και τις πολυπλοκότητες του. Στη συνέχεια διεξάγουμε μια εις βάθος εξέταση των αιολικών παραγώγων, αναφέροντας λεπτομερώς τη φύση τους, την ιστορική τους εξέλιξη, τις ποικίλες εφαρμογές και τις μεθόδους αποτίμησής τους. Μια πρακτική προσομοίωση με επίκεντρο το αιολικό πάρκο του Παναχαϊκού στην Ελλάδα απεικονίζει την εφαρμογή των αιολικών παραγώγων, ιδιαίτερα στη διαχείριση των διακυμάνσεων των εσόδων που προκύπτουν από τη μεταβλητότητα του ανέμου. Σε όλο αυτό το ταξίδι, τονίζεται η σημασία της αιολικής ενέργειας στην παγκόσμια μετάβαση προς καθαρές και βιώσιμες πηγές ενέργειας, τονίζοντας τις δυνατότητές της να μειώσει τις εκπομπές αερίων του θερμοκηπίου και να καταπολεμήσει την κλιματική αλλαγή. Οι παραδοσιακές στρατηγικές μετριασμού του κινδύνου, συμπεριλαμβανομένης της ασφάλισης, έρχονται σε αντίθεση με την προληπτική και προσαρμοσμένη προσέγγιση που προσφέρουν τα χρηματοοικονομικά παράγωγα, ιδιαίτερα τα αιολικά παράγωγα. Αυτά τα όργανα παρουσιάζονται ως ισχυρά εργαλεία για την αντιμετώπιση των μοναδικών προκλήσεων της βιομηχανίας αιολικής ενέργειας, λόγω της προσαρμοστικότητας και της ικανότητάς τους να ενεργοποιούνται βάσει προκαθορισμένων συνθηκών. Τα αποτελέσματα της προσομοίωσης υπογραμμίζουν την αποτελεσματικότητα των ασιατικών επιλογών ως εργαλείων διαχείρισης κινδύνου στον τομέα της αιολικής ενέργειας, ειδικά υπό συνθήκες ελάχιστης ταχύτητας ανέμου. Καθώς ο κόσμος συνεχίζει να αγκαλιάζει τις ανανεώσιμες πηγές ενέργειας, τα αιολικά παράγωγα είναι έτοιμα να καταστούν απαραίτητα για τη διασφάλιση της βιωσιμότητας και της κερδοφορίας των έργων αιολικής ενέργειας. Ωστόσο, η υιοθέτησή τους απαιτεί μια λεπτή κατανόηση των καιρικών προτύπων, των χρηματοπιστωτικών αγορών και των ρυθμιστικών πλαισίων. Αυτή η διατριβή παρέχει μια σταθερή βάση για την κατανόηση των θεμελιωδών αρχών της αιολικής ενέργειας, των στρατηγικών διαχείρισης κινδύνου και της πρακτικής χρήσης των αιολικών παραγώγων. Θέτει το έδαφος για μελλοντική έρευνα σχετικά με την πολυπλοκότητα και τις αποχρώσεις των αιολικών παραγώγων, τη δυνατότητα εφαρμογής τους σε διάφορες γεωγραφικές περιοχές και εγκαταστάσεις αιολικών πάρκων και τη μακροπρόθεσμη αποτελεσματικότητά τους στη διαχείριση κινδύνων που σχετίζονται με τον άνεμο. Συμπερασματικά, καθώς ο τομέας της αιολικής ενέργειας συνεχίζει να αναπτύσσεται, η ενσωμάτωση των αιολικών παραγώγων στις πρακτικές διαχείρισης κινδύνου είναι απαραίτητη για την ενίσχυση της κερδοφορίας, της σταθερότητας και του ευρύτερου στόχου του μετριασμού της κλιματικής αλλαγής μέσω ανανεώσιμων πηγών ενέργειας.

**Λέξεις-κλειδιά**: Αιολικά Παράγωγα, Ανανεώσιμες Πηγές Ενέργειας, Χρηματοοικονομικά Μέσα, Ασιατικά Δικαιώματα Προαίρεσης, Λειτουργίες Αιολικών Πάρκων

**Abstract**

This dissertation presents a comprehensive exploration of wind energy fundamentals and their integration with risk management, focusing on the pivotal role of wind derivatives in mitigating wind-related risks. Beginning with an elucidation of the foundational principles of wind energy, we delve into the intricate world of risk management in the wind energy sector, recognizing its unique challenges and complexities. We subsequently conduct an in-depth examination of wind derivatives, detailing their nature, historical evolution, diverse applications, and valuation methods. A practical simulation centered on the Panachaiko wind farm in Greece illustrates the application of wind derivatives, particularly in managing revenue fluctuations resulting from wind variability. Throughout this journey, the significance of wind energy in the global transition towards clean and sustainable energy sources is highlighted, emphasizing its potential to reduce greenhouse gas emissions and combat climate change. Traditional risk mitigation strategies, including insurance, are contrasted with the proactive and tailored approach offered by financial derivatives, particularly wind derivatives. These instruments are showcased as powerful tools for addressing the unique challenges of the wind energy industry, owing to their adaptability and ability to activate based on predefined conditions. The simulation results underscore the effectiveness of Asian options as risk management tools in the wind energy sector, especially under minimal wind speed conditions. As the world continues to embrace renewable energy sources, wind derivatives are poised to become indispensable in ensuring the sustainability and profitability of wind energy projects. Nevertheless, their adoption requires a nuanced understanding of weather patterns, financial markets, and regulatory frameworks. This dissertation provides a solid foundation for comprehending wind energy fundamentals, risk management strategies, and the practical utilization of wind derivatives. It sets the stage for future research into the complexities and nuances of wind derivatives, their applicability in diverse geographical regions and wind farm setups, and their long-term effectiveness in managing wind-related risks. In conclusion, as the wind energy sector continues to grow, the integration of wind derivatives into risk management practices is essential for enhancing project profitability, stability, and the broader goal of mitigating climate change through renewable energy sources.

**Keywords**: Wind Derivatives, Renewable Energy, Financial Instruments, Asian Options, Wind Farm Operations

# Table of Contents

# Chapter 1. Introduction

Financial markets represent the heartbeat of modern economies, providing a vital platform for the exchange of financial assets, capital allocation, risk management, and price discovery (Kindleberger, 1993; Ferguson, 2008). These markets facilitate interactions among diverse stakeholders, ranging from individual investors to multinational corporations and governments. Moreover, the evolution of financial markets has given rise to complex financial instruments known as derivatives, which have transformed the landscape of risk management and investment strategies. In recent years, the convergence of finance and climate science has birthed an innovative subfield within derivatives—weather derivatives—that allow market participants to hedge against the uncertainties posed by climatic fluctuations.

The roots of financial markets can be traced back to ancient civilizations, where rudimentary forms of trading and credit systems existed. However, the formalization and expansion of financial markets gained momentum during the medieval and Renaissance periods. Works such as Charles Kindleberger's seminal book "A Financial History of Western Europe" (Kindleberger, 1993) provide invaluable insights into the historical evolution of financial markets and the interconnectedness between finance and economic development. Kindleberger's exploration of financial crises, market dynamics, and the role of innovations offers a rich historical context for understanding the emergence of today's global financial landscape.

Another prominent figure in understanding financial market history is Niall Ferguson, whose work "The Ascent of Money" (Ferguson, 2008) presents a comprehensive account of the evolution of money, credit, and financial systems. Ferguson's analysis underscores the transformative role of financial markets in shaping societies, industries, and global power structures. By examining the historical trajectory of financial markets, scholars gain a deeper appreciation for the factors that have shaped their contemporary forms and functions.

The advent of financial derivatives marked a revolutionary shift in the way risk is managed and financial transactions are structured. These instruments derive their value from underlying assets, providing opportunities for investors to speculate on price movements, hedge against risks, and optimize their investment portfolios. Hull's renowned work "Options, Futures, and Other Derivatives" (Hull, 2018) serves as a fundamental resource for understanding the conceptual framework and mechanics of various financial derivatives. Hull's exploration of derivatives' role in managing market risks and enhancing investment strategies provides a robust foundation for comprehending the intricacies of these instruments.

Additionally, John C. Hull's academic contribution extends to "Risk Management and Financial Institutions" (Hull, 2012), a comprehensive guide that delves into risk management strategies employed by financial institutions. By examining the practices and methodologies utilized by banks, insurance companies, and investment firms, Hull sheds light on the pivotal role derivatives play in shaping risk mitigation strategies across the financial landscape.

Michael McDonald's work "Derivatives Markets" (McDonald, 2013) offers another authoritative perspective on financial derivatives. McDonald's book explores derivatives' underlying concepts, market structures, and trading strategies, catering to both academic scholars and practitioners seeking a comprehensive understanding of these instruments. By engaging with these scholarly works, researchers gain insights into the multifaceted nature of derivatives and their pervasive influence on modern financial systems.

In an era marked by heightened awareness of climate change and its socioeconomic ramifications, the integration of finance and climate science has yielded innovative instruments known as weather derivatives. These derivatives provide a means to hedge against weather-related risks, offering protection to sectors vulnerable to climatic fluctuations. The work of Robert S. Cummins and Richard M. Trainor in "Weather Derivatives: Managing Weather-Related Risks" (Cummins & Trainor, 2011) serves as a cornerstone for understanding the conceptual framework and application of weather derivatives. Cummins and Trainor's exploration of weather derivative contracts, pricing mechanisms, and risk management strategies equips researchers with insights into the intricate interplay between climate variability and financial instruments.

This dissertation is organized as follows:

- Chapter 2: Global Financial Markets: This chapter examines the historical evidence of financial markets, the diverse array of products and services they offer, and an analysis of the most developed global financial markets. The chapter explores indices of market performance and provides insights into the evolution of derivatives markets within these financial ecosystems.

- Chapter 3: Financial Derivatives: Delving into the realm of financial derivatives, this chapter delves into the fundamental characteristics of derivatives and distinguishes between exchange-traded and over-the-counter derivatives. It comprehensively examines various types of derivatives, including futures, forwards, swaps, and options, while exploring their roles in risk management and speculation.
- Chapter 4: Wind Derivatives: Focusing on the intersection of finance and climate, this chapter delves into weather derivatives, with a specific focus on wind derivatives. The chapter traces the historical development of weather derivatives, discusses wind indexes as benchmarks, and analyzes the mechanics of exchange-traded and over-the-counter wind derivatives.
- Chapter 5: Conclusion: Synthesizing the findings from the preceding chapters, this concluding chapter reflects on the interconnectedness of financial markets, derivatives, and weather derivatives. It highlights the implications of these interconnections for financial practitioners, policymakers, and researchers, while also suggesting avenues for future research and exploration.

# Chapter 2. Global Financial Markets

## 2.1 Historical Evidence of Financial Markets

The development of money and capital markets is the result of many thousands of years of development and mainly the result of the need for commercial transactions in an internationalized commercial and economic system. The first societies were based on self-production and self-consumption. However, the exchange of goods was imperative in order to serve the needs of all members of society. This system created the society of anti-pragmatism. But the main problem that was created was that all participants of the market and society did not have the same needs and so soon the exchange of goods was replaced by the exchange of goods for materials of great value. The greatest importance was attached both to precious metals, such as gold, silver and copper, and to rare materials, such as silk, dyes and spices. The development of international trade in its early stages did not favor the dominance of trade in precious metals alone. However, soon the first money and especially the first coins were based on precious metals as their main component (Wray, 1999; Davies, 2010).

This development of trade gradually led to the creation of centers of trade, i.e., large markets, where participants paid rent, while large funds were gradually created. Now, two major problems began to arise, which concerned both the authenticity of the money and its storage. In this way, the first system of state mints and central banks (not in today's sense of supervision, but in the sense of a central treasury) was created. The first mints operated under the supervision of the monarch or governor of a region and for this reason their face was often depicted on one side of the coin. The weight of the coins was specific and thus their authenticity could be checked. With reference to the first treasuries, evidence is presented that both in ancient Greece and in ancient Rome, temples functioned in this way as well (Chown and Chown, 1994; Andreau, 1999).

The evolution of the above system led during the late Middle Ages to the creation of pre-banks. The first banks appear in Italy and soon in Spain and other European countries. Of course, the acquisitions of the European states in other regions, as well as the international commercial activity led to the spread of this system. Through this long evolution of trade and commerce, the financial system emerged. The increase in the volume of transactions and their complexity have led to the development of specialized markets that include investment and financial products and services (Hodgett, 2013).

The financial system includes a number of individual systems, in such a way that the identification with terms such as: banking system, insurance system, etc., does not correspond to the overall dimension, composition, organization and operation of the overall financial system. The analysis of this includes the means, services and mechanism of transfer of monetary resources from surplus to deficit units, which characterizes the above system as a system of transformation and redistribution of savings and fixed investments.

In the above system there are eight main participants: The first category concerns banks, stock exchanges and supervisory authorities (state, independent authorities, central banks). The second category focuses more on those who actively participate in the money and capital markets. These are households and businesses, in the sense of consumers and savers, businesses as listed on money markets, investors, commodities, and money in the sense of capital for investment and the purchase of commodities. Both the last two of course are the main means to achieve the purpose and goals of the first three participants of the second category. As will be discussed below, all participants in both categories lead to an organized, functional, efficient and effective financial system.

The first stock exchanges were created with the aim of bringing together the needs of businesses for additional capital and investors who aimed to profit from the revenues, activities and profits of the businesses in which they invested. This is both the way, and also the reason, with which the stock markets operate to this day. Stock markets are therefore characterized as capital markets. The supervision of stock markets today is carried out through an independent authority, usually called the "capital market commission", but also the company that manages the transactions and the participants in them.

The first derivatives markets were created with the aim of uniting businesses, investors and commodities, with a common reference being money, in a single system. Investors (in the sense of natural persons as well as companies) participate in them, aiming at risk hedging, margin trading, speculation and risk-free speculation (arbitrage).

The first non-organized derivatives market appeared in Babylon in ancient Mesopotamia, through the Code of Hammurabi. This code allowed for the sale of goods and assets for delivery at an agreed price at a future date, required that contracts be in writing and be witnessed, and allowed for the awarding of contracts for works and commercial activities. The first use of such contracts for speculation is shown in ancient Greece by Thales (De Bruin et al., 2018). Thales had developed a device and a forecasting model regarding the olive harvest. In this way he made agreements with mill owners to deposit his money with them, to guarantee the exclusive use of their mills. The above contract was successful because no mill owner knew what the harvest would be and thus Thales successfully negotiated low prices because a harvest was in the future, while the owners had a desire to secure an income to offset the possibility of a poor yield. However, under the terms of the contracts, Thales was not obliged to use the mills if the yield was poor. These contracts are more like modern options (Fard, 2014).

The first modern organized market was introduced in 1710 in Osaka, Japan. In this particular derivatives market, rice prices were traded for future production. Producers aimed to secure payment for their crop at a certain amount, while traders wanted to ensure the delivery of a certain amount of produce at a certain price (Kummer and Pauletto, 2012). With roots in 1571, the London Metal Exchange first opened in 1877. Main trading commodities were initially copper, then lead and zinc. After the end of World War II, the range of commodities expanded to include nickel, aluminum, tin, steel, cobalt and molybdenum (Keen, 2000; Riederova and Ruzickova, 2011).

The world's largest derivatives market is based in Chicago and operated by the CME Group. The reason for its creation was mainly the position of the city as a center of transport, distribution and marketing of agricultural products. This particular market has its roots in 1848 and the Chicago Board of Trade. The first contracts were corn futures. In 1919 the entire Chicago derivatives market was reorganized as the Chicago Mercantile Exchange (CME). In this market, after the fall of the system of fixed exchange rates, futures contracts in foreign currencies such as the British pound, the Canadian dollar, the mark, the yen and the Swiss franc began to be traded (MacKenzie and Millo, 2003; Kummer and Pauletto, 2012; Lee and Martin, 2016).

## 2.2 Products and Services

In order to explain how money and capital markets work, as well as the products and services provided in them, the participants that make up the above markets should first be explained. Participants are divided into four categories: commercial banks, investment banks, markets and organizations that supervise and act as intermediaries in money and capital markets. Commercial banks, also called retail banks, are financial institutions that accept deposits from households and businesses, i.e., the public, and issue loans for consumption and investment purposes, with the aim of making a profit. Profits come from the spread, i.e., the difference between the interest rate they pay on deposits and the interest they charge on loans, as well as other fees, such as the transaction fee and the application fee for a loan. Commercial banks are often found as branches of a large bank, dealing with large or medium-sized companies. Essentially, in this way banks act as intermediaries of money supply and demand. The main products provided by commercial banks are various variants of deposit accounts (such as current, savings and closed savings accounts), the issuance of loans, but also related activities such as the provision of collateral (Tobin, 1963; Huete and Roth, 1988; Barr et al., 2002).

Investment banks are large financial institutions and financial services companies. Their activities include financial transactions, advisory services and lending to high net-worth individuals, large corporations and governments. The main products of investment banking are large loans, large premiums, the issuance of derivatives not traded in an organized market, the issuance of bonds and the issuance of shares in the primary market. Their role is also important in the acquisitions and mergers of large companies, which are often financed by investment banks. Finally, many investment banks maintain brokerage and asset management departments in conjunction with investment research businesses. Unlike commercial banks, investment banks do not take deposits. Instead, their reserves as well as their profits come from the fee you agree to perform the above tasks and services they provide. Investment banking is divided into two axes, selling and buying. Selling includes trading securities for cash or in facilitating transactions and market making, securities promotion and underwriting services. The purchase includes the provision of consulting services. Mutual funds, insurance services, unit trusts and hedge funds are the most common types of market entities (Ritter, 2003; Liaw, 2011; Iannotta, 2014).

Markets are divided into five categories. These are stock markets, bond markets, commodity markets, foreign exchange markets and derivatives markets. Stock markets, are the most common form of capital purchase. These markets are attended by the public, investors and the companies listed on them. In order for a company's stock to be traded, it must have been listed through a process called an initial public offering (IPO) (Yung et al., 2008). This process is the work of investment banks. After the stock is listed, the public and investors can freely buy and sell a certain number of shares of the listed companies. Because of this process stock markets are classified as secondary markets (Naughton, 1999).

Bonds are fixed income securities. This is because their price depends on a specific interest rate, which is called the bond yield, and in some cases on a fixed amount that is provided at the end of a specific period (for example, every six months or on an annual basis) and which is called coupon. Bonds are traded in secondary markets, which are organized just like the stock exchanges, discussed above. The listing of the bonds takes place through an auction process, which is carried out by investment banks if it is a corporate bond, or by the relevant department of the finance ministry or the central bank of a country if it is a government bond. The bond yield is usually a product of free negotiation between investors, who buy or sell the particular securities (Fabozzi and Fabozzi, 2021).

Commodity markets are trading places usually based on options which are written or exercised on a product. For example, the price of oil is a result of trading futures contracts, which usually expire during the current month or at the end of the current month. In general, there are 10 categories of goods that are the subject of organized transactions. These are fossil fuels, oils, refined products, electricity, mechanical equipment, plastics, pharmaceuticals, chemicals, metals and high value products. There are seven commodity categories, namely seeds, food and yarn, livestock and meat, all energy products, forestry products, metals (divided into industrial and precious) and other products, such as palm oil, amber, rubber and wool (Domanski and Heath, 2007; Cheng and Xiong, 2014).

The foreign exchange market is the largest decentralized market in the world. It is a market in which the major commercial banks and investment banks participate mainly. It is a market where participants buy and sell domestic and foreign currency at one price. The specific price expresses the exchange rate of a specific pair of currencies that are traded. The operation of the foreign exchange market is particularly important for international trade as it allows participants to facilitate their transactions (Hodrick, 2014).

Derivatives markets are divided into two categories, with the first referring to transactions that take place in an organized money market and the second referring to transactions that take place outside the market (Over-the-Counter, OTC). As will be explained below, derivatives are so called because their value comes from another value. The underlying value comes either from the stock market, i.e., the difference in the share price, or from the bond market, i.e., it concerns their performance, or from the commodity market, i.e., it concerns the price of the commodity, or from the foreign exchange market, i.e., it concerns the exchange rate of two currencies. Of course, the evolution of international markets has led to the existence of derivatives with other underlying values. Regarding derivatives, they are divided into three major categories. The first relates to futures and forwards, the second to swaps and the third to options (Remolona, 1992; Golez, 2014; Atilgan et al., 2016). All categories and subcategories will be analyzed in the next chapter.

Certain types of markets and certain types of products traded in them require the assistance of an intermediary, whose role is multiple. In the case of investment banks, their contribution to the underwriting of securities and contracts is significant. However, many times they act as overseers or supervisors of a sale transaction, where they supervise the participants in it so that all the terms of the contract are fulfilled at its expiration. For this specific activity there are facilities called clearing houses. The final participant in international markets is the supervisor. The role of the supervisor is usually undertaken by an independent authority in each country. In most cases this authority is the capital market committee, which is charged with the task of supervising the participants and the trading conditions, so that none of the participants are harmed due to the malicious actions of other participants (Mendelson, 1982; Geva, 1991; Merton, 1995; Costantino, 2012; Szegedi, 2012; Greenbaum et al., 2015).

## 2.3 Most Developed Global Financial Markets

### *2.3.1 By products listed*

The roots of modern financial markets trace back to the 17th century, when stock markets began to emerge in various European cities, including Amsterdam and London. These markets initially facilitated the trading of shares in individual companies, laying the foundation for the future development of financial instruments. As economies expanded and industrialization took hold, new forms of securities emerged, such as bonds and derivatives, contributing to the diversification of financial markets.

The 20th century marked significant milestones in the development of global financial markets. The establishment of central banks, regulatory bodies, and standardized accounting practices provided a stable framework for market operations. The New York Stock Exchange (NYSE), founded in 1792, emerged as a global financial hub, becoming a symbol of capitalism's vigor. The advent of electronic trading in the late 20th century revolutionized market access, enabling faster and more efficient trading across borders.

Today, several financial markets have achieved unparalleled levels of development and sophistication, offering an extensive range of products for investors to trade. Three of the most prominent and diverse markets in this regard are the New York Stock Exchange (NYSE), the London Stock Exchange (LSE), and the Chicago Mercantile Exchange (CME).

The NYSE stands as one of the world's oldest and most influential financial markets. With a history spanning over two centuries, it has evolved into a diverse marketplace offering a wide array of financial products. While it began as a platform for equities trading, the NYSE now lists a variety of instruments, including exchange-traded funds (ETFs), options, bonds, and American depositary receipts (ADRs). The NYSE has adapted to technological advancements by transitioning to electronic trading platforms, which have enhanced market liquidity and accessibility.

The London Stock Exchange, with origins dating back to the late 17th century, has transformed into a global financial powerhouse. Similar to the NYSE, the LSE has expanded its offerings beyond traditional equities. It lists an array of products, including equities, bonds, derivatives, and ETFs. The LSE's prominence as a hub for international listings has been bolstered by its diverse range of financial instruments, attracting investors from around the world.

The Chicago Mercantile Exchange, founded in 1898, has played a vital role in the development of derivative markets. Specializing in commodities and futures contracts, the CME enables investors to trade contracts on a wide range of assets, including agricultural products, energy, metals, and financial indices. The introduction of financial derivatives, such as futures and options, has enabled investors to manage risk and speculate on price movements. The CME's products have become essential tools for corporations and individuals seeking to hedge against market volatility.

The development of these markets has been marked by an ever-expanding range of financial products that cater to different investor preferences and risk profiles. These products can be broadly categorized into equities, fixed income, derivatives, and exchange-traded funds (ETFs).

*2.3.2 By total performance*

The profitability of a stock exchange is influenced by an array of factors, encompassing trading volumes, listing fees, transaction charges, and the market's attractiveness to investors. Some of the world's most profitable stock exchanges have established their dominance through innovative offerings and strategic positioning.

The New York Stock Exchange (NYSE) stands as an emblematic example of a highly profitable stock exchange. Founded in 1792, it has evolved into a global marketplace that lists equities, exchange-traded funds (ETFs), and other financial instruments. Its profitability is underpinned by robust trading volumes, attracting a diverse range of market participants, from institutional investors to individual traders. The NYSE's revenues are substantially bolstered by listing fees, initial public offerings (IPOs), and ongoing maintenance fees. In recent years, the NYSE has made substantial investments in cutting-edge technology to enhance trading efficiency and resilience, further solidifying its status as a profitable exchange. As of the latest available data, the NYSE generated revenues of approximately $2.4 billion in 2021.

The NASDAQ, founded in 1971, has carved its niche as a profitable stock exchange with a strong emphasis on technology companies. Renowned for its electronic trading platform, the NASDAQ has established itself as a leading marketplace for technology-related IPOs and high-growth firms seeking capital infusion. Its profitability is derived from transaction fees, market data services, and listing fees. The NASDAQ's electronic trading platform has attracted traders seeking fast and efficient execution, while the presence of tech giants such as Amazon, Apple, and Microsoft on its exchange has contributed to its profitability. In 2021, NASDAQ reported revenues of around $3.7 billion, highlighting its strong financial performance.

The Hong Kong Stock Exchange (HKEX) serves as a pivotal gateway to China's capital markets, making it a critical player in the region's financial landscape. Its profitability is intricately linked to its role as an international hub for investors seeking exposure to Chinese companies. The HKEX's profitability is sourced from trading fees, IPO fees, and market data services. Its strategic location, coupled with its ability to attract mainland Chinese companies seeking global listings, has positioned it as a lucrative platform for investors eager to tap into China's economic growth. In the fiscal year 2020-2021, HKEX reported revenues of approximately $2.8 billion.

Derivatives exchanges play a pivotal role in offering platforms for trading derivatives instruments, including futures contracts and options contracts. These exchanges derive profitability from transaction fees, contract trading volumes, and supplementary value-added services.

The Chicago Mercantile Exchange (CME) is a titan in the derivatives arena, with a rich history tracing back to 1898. Specializing in derivatives contracts linked to an extensive range of assets, including commodities, interest rates, equity indices, and foreign exchange, the CME has garnered its profitability from its diverse product offerings and global reach. Catering to both institutional and retail traders, its profitability is driven by trading fees, clearing fees, and data services. The CME's proficiency in providing risk management tools for market participants and its role in price discovery further reinforce its standing. As of the latest available data, the CME reported revenues of approximately $4.9 billion in 2021.

Eurex Exchange, headquartered in Frankfurt, Germany, is a prominent derivatives exchange in Europe. It boasts a comprehensive array of derivatives products, ranging from equity derivatives to interest rate derivatives and commodities derivatives. Eurex's profitability is rooted in its substantial presence in the European derivatives market and its dedication to innovative offerings and services. Its close proximity to major European financial institutions and its robust risk management protocols have contributed to its reputation and profitability. In 2020, Eurex reported revenues of around $1.5 billion.

The Intercontinental Exchange (ICE) operates a multitude of exchanges and clearinghouses, focusing on energy commodities, agricultural products, and financial derivatives. ICE's global presence, offering a platform for trading and clearing a diverse array of derivatives products, is a key driver of its profitability. Its electronic trading platforms and data services cater to the needs of traders, risk managers, and investors alike. Strategic acquisitions and expansions into new markets have further propelled ICE's profitability. In 2020, ICE reported revenues of approximately $6.8 billion.

*2.3.3 By trade volume*

Trade volume serves as a key indicator of an exchange's activity and significance. Several stock exchanges have gained prominence due to their substantial trade volumes and the role they play in the global economy.

The New York Stock Exchange (NYSE) stands as the largest and most renowned stock exchange in the world by trade volume. Founded in 1792, the NYSE has evolved into a global financial hub, attracting a diverse range of investors from institutional giants to individual traders. Its trade volume is a testament to its position as a primary venue for trading equities, exchange-traded funds (ETFs), and other financial instruments. As of the latest available data, the NYSE boasts an average daily trade volume of around $90 billion, affirming its dominance in the financial world.

The NASDAQ, characterized by its electronic trading platform and focus on technology companies, ranks among the top stock exchanges by trade volume. Renowned for its role in hosting technology-related IPOs and its appeal to high-growth firms, the NASDAQ has become a symbol of innovation. Its trade volume underscores its significance, with an average daily trade volume of approximately $170 billion. This substantial trade volume reflects the market's preference for electronic trading and the influence of tech giants that call the NASDAQ home.

he Shanghai Stock Exchange (SSE) represents China's primary stock exchange and is a major player in global trade volume rankings. Established in 1990, the SSE has experienced rapid growth, reflecting China's economic expansion. The SSE's trade volume is driven by its significance as a platform for trading Chinese A-shares, which are open to domestic and some international investors. With an average daily trade volume of around $110 billion, the SSE exemplifies China's growing influence on the global financial stage.

Trade volume in derivatives exchanges is a reflection of market participants' engagement in risk management, speculation, and investment strategies.

The Chicago Mercantile Exchange (CME) is a dominant player in the derivatives market, boasting substantial trade volume and an extensive range of derivatives products. Established in 1898, the CME is renowned for its offerings in commodities, interest rates, equity indices, and foreign exchange derivatives. Its trade volume is a testament to its global prominence, with an average daily trade volume of approximately $5 trillion. The CME's ability to provide risk management tools and serve as a price discovery platform contributes to its robust trade volume.

Eurex Exchange, based in Frankfurt, Germany, ranks among the largest derivatives exchanges globally by trade volume. Specializing in a variety of derivatives products, including equity derivatives and interest rate derivatives, Eurex is a prominent player in the European derivatives landscape. Its average daily trade volume stands at around $300 billion, reflecting its importance to institutional and retail traders seeking exposure to diverse derivatives instruments.

B3, formerly known as BM&FBOVESPA, is the leading derivatives and equities exchange in Latin America, operating in Brazil. Established through the merger of various Brazilian exchanges, B3 plays a pivotal role in the region's financial ecosystem. With an average daily trade volume of approximately $100 billion, B3 is a significant contributor to derivatives trading in emerging markets. Its diverse offerings, including commodities, interest rates, and equity derivatives, attract market participants seeking exposure to the Brazilian market.

#### *2.3.4 Most developed derivatives markets*

The Chicago Mercantile Exchange (CME) is undeniably one of the most developed and prominent derivatives markets globally. Established in 1898, the CME has played a pivotal role in shaping the derivatives landscape. Its significance lies in its diverse range of derivatives products, encompassing commodities, interest rates, equity indices, and foreign exchange. The CME's offerings cater to a wide spectrum of market participants, from hedgers seeking risk management tools to speculators aiming to capitalize on price movements. The CME's development can be attributed to its commitment to innovation, risk management, and market integrity. Its futures and options contracts on agricultural commodities such as corn, soybeans, and livestock have allowed farmers to hedge against price fluctuations. Additionally, its interest rate derivatives, including

Treasury futures and Eurodollar futures, are crucial tools for managing interest rate exposure for financial institutions. One of the standout features of the CME is its electronic trading platform, which has revolutionized derivatives trading by enabling rapid execution and global access. The CME's electronic platform has not only boosted its trade volume but has also enhanced its appeal to both institutional and retail traders.

Eurex Exchange, headquartered in Frankfurt, Germany, is another prime example of a highly developed derivatives market. Founded in 1998, Eurex has established itself as a dominant force in the European derivatives landscape. Its offerings encompass equity derivatives, interest rate derivatives, and equity index derivatives, making it a comprehensive platform for derivatives trading. Eurex's development has been shaped by its proximity to major European financial institutions and its commitment to innovation. Its role as a central counterparty ensures efficient clearing and risk management for market participants. Eurex's benchmark products, such as EURO STOXX 50 and DAX futures, have gained widespread recognition among investors seeking exposure to European equity markets. Furthermore, Eurex's introduction of pioneering products, such as futures on environmental, social, and governance (ESG) indices, underscores its responsiveness to market trends. These initiatives have contributed to Eurex's reputation as a forward-thinking and developed derivatives market.

The Hong Kong Exchanges and Clearing (HKEX) is a crucial player in the derivatives markets, serving as a bridge between international investors and China's capital markets. HKEX's development is intertwined with its role in offering derivatives products linked to the Chinese market. Its derivatives offerings include equity derivatives, commodity derivatives, and currency derivatives. One of HKEX's standout developments is the introduction of Stock Connect programs, which enable international investors to access China's A-share market. The launch of futures contracts linked to A-shares has provided a platform for managing risk and gaining exposure to Chinese equities. Additionally, the introduction of RMB currency futures has allowed traders to hedge against currency fluctuations. HKEX's strategic location and its ability to facilitate cross-border trading have been pivotal to its development. The exchange's development aligns with China's growing influence in the global economy and its efforts to internationalize its financial markets.

The development of derivatives markets around the world has been driven by innovation, accessibility, and the evolving needs of market participants. The Chicago Mercantile Exchange (CME), Eurex Exchange, and Hong Kong Exchanges and Clearing (HKEX) are prime examples of highly developed derivatives markets, each with its unique characteristics and offerings. The CME's diverse range of derivatives products and its electronic trading platform have contributed to its prominence in the derivatives landscape. Eurex Exchange's strategic location, innovative products, and focus on risk management have solidified its position in the European derivatives market. HKEX's role as a bridge between international investors and China's capital markets highlights its significance in facilitating cross-border trading. As the derivatives landscape continues to evolve, these developed markets serve as models of success, influencing the direction of derivatives trading, risk management, and investment strategies on a global scale.

# Chapter 3. Financial Derivatives

## 3.1 What Are Financial Derivatives

Parallel to the operation of stock market values, the operation of so-called stock market derivatives is observed. As mentioned in the previous chapter, financial derivatives are property securities, whose price and performance depend on an underlying asset price. The underlying asset can be any stock, loan rate, bond yield, exchange rate, commodity price, but also any other measurable quantity. In recent years, the development of derivatives with an underlying value other derivative products (derivatives on derivatives), or even the occurrence or the possibility of occurrence of certain events, has been observed (Nunez et al., 2018).

The first forms mentioned above concern simple derivative forms. These are products which, as mentioned in the previous chapter, existed even from ancient times. Simple derivatives are actually contracts signed between two parties, where one has the obligation to deliver the underlying value while the other party has the obligation to pay at a pre-agreed price. The above simple consideration is observed in two types of derivatives, futures and forwards. A slightly more complex consideration comes from the operations of exchanging two values. An example of such a swap is the swap between a floating and a fixed interest rate. This is also the simple version of swaps contracts. However, the specific contracts appeared as a result of the evolution of the financial system and not the needs of the investors themselves (Hund and Kennedy, 2004).

Contrary to the above view, i.e. as a result of the evolution of investors' needs, options appeared. Specific derivatives refer to contracts in which the right and not the obligation to buy or sell an underlying value is signed, at a predetermined price, at a predetermined time period or moment. The fact that the owner of such a contract has no obligation makes these contracts primarily tools for hedging risk or speculation (Chakravarty et al., 2004).

In financial derivatives, there is a distinction between those traded and cleared in an organized money market (exchange traded derivatives) and those based on agreements between two parties, and traded outside the money market (over the counter, OTC). The main difference between the two is that in the first case there is a clearing house, i.e. an organization that supervises the correct execution of the contracts and the full fulfillment of the terms, while in the second case the above structure does not exist. The fact that OTC derivatives are not traded on an organized market makes them easy to interfere with the terms of the contracts, a fact from which significant variants of options have arisen (Banks, 2005; Atkeson et al., 2015).

An example of interventions is the fact that in the above first category as underlying values are presented the prices and performance of assets whose prices are already traded on an organized market. On the contrary, in the second case values can arise which are based even on the facts. Examples of such events are cases of bankruptcy, but even the climatic conditions of an area. Also, the above products can be settled not only at their expiration (European options), but at any date up to their expiration (American options) or even on specific dates from their registration until their expiration (Bermuda options) . The analysis of all the above will follow in the next sections of this chapter (Marinkivic, 2011).

## 3.2 Distinction Between Exchange-Traded and OTC Derivatives

Organized financial derivatives markets operate with contracts drawn up between members and the entire market, while brokerage contracts have the guarantee of the market and the sales in which they are subject to negotiation. Each product has the same characteristics, while the standardization that exists in the organized financial markets makes them interchangeable, thus providing liquidity and the possibility of netting. As a result of trading on organized exchanges, futures contracts are largely standardized. Standardization has to do mainly with three factors, concerning when the delivery will take place, where it will take place and exactly what will be delivered.

The advantages of standardization are multiple, as it is essential for the smooth functioning of trading in the secondary market, since all participants exchange rights contracts based on equal terms and thus contracts are exchanged with ease. Then there is the potential for higher contract and transaction sizes, since the buying and selling processes are simpler to manage. Finally, transaction costs are lower since the parties do not negotiate the terms every time a contract is signed and completed. Another advantage of organized money markets is the daily settlement. This means that a margin account is maintained, which must have a certain amount of balance daily. Thus, positions that have losses pay the amount of the loss, while positions that have profits can and do continuously draw the running profit (Birdthistle, 2008; Baiden, 2011).

OTC agreements refer to agreements concluded between organizations and customers and not through organized markets and customers. These agreements used to operate over a telephone network and have now moved to computer networks owned by financial institutions, businesses and fund managers. Unlike the previous form, these contracts are not standardized and thus there is a credit risk. However, OTC contracts also have certain benefits, such as the freedom that investors have to determine the terms of the contracts, as well as ensuring confidentiality in their transactions. Key disadvantages of OTC contracts are insufficient control and lack of transparency, lack of precautionary rules, no product approval body and no clearing body (Cecchetti et al., 2009; Gregory, 2014).

## 3.3 Futures

Futures contracts are integral components of financial markets, serving as instruments for risk management, price discovery, and speculation. This literature review explores the various facets of futures contracts, including their history, mechanics, role in risk management, and impact on market efficiency. The review draws upon academic books and articles from reputable journals to provide a comprehensive understanding of the subject.

The roots of futures contracts can be traced back to ancient civilizations engaging in forward agreements to secure future prices for commodities. However, the modern futures market as we know it today began to take shape in the late 19th century. Mayer (2018) highlights that the establishment of organized futures exchanges, such as the Chicago Board of Trade (CBOT), played a pivotal role in formalizing standardized contracts with predetermined terms. The futures market's evolution was driven by the need for agricultural producers and consumers to manage the risks associated with price fluctuations.

A key characteristic of futures contracts is their standardized nature, including contract size, expiration date, and settlement mechanisms. Hull (2018) explains that the standardization of these contracts enables efficient trading on organized exchanges, facilitating price discovery and enhancing market liquidity. Futures contracts are typically marked-to-market daily, resulting in gains and losses being settled on a daily basis. This process, known as margining, helps ensure that both parties maintain adequate collateral to cover potential losses.

Futures contracts serve as powerful tools for risk management and hedging. When discussing risk management, Leland (1999) emphasizes that futures contracts allow market participants to lock in future prices, thereby reducing exposure to price volatility. Agricultural producers, for instance, can use futures contracts to hedge against adverse price movements, ensuring a predictable revenue stream. Similarly, financial institutions can hedge against interest rate fluctuations by utilizing interest rate futures.

While futures contracts are widely used for risk management, they also play a significant role in speculation and price discovery. Black (1986) discusses how speculators in the futures market provide liquidity and contribute to efficient price discovery. Speculative activities help bridge the gap between buyers and sellers, enabling smooth trading and accurate price determination. This is particularly evident in financial futures markets, where traders speculate on the future direction of stock indices, interest rates, and currencies.

The introduction of futures contracts has been linked to improvements in market efficiency. Fama (1970) introduced the concept of the "efficient market hypothesis," suggesting that futures markets contribute to the rapid incorporation of new information into asset prices. Futures contracts allow investors to express their views on future price movements, enhancing the speed at which market prices adjust to new information.

Futures contracts are foundational instruments in financial markets, offering benefits such as risk management, price discovery, and speculation. The historical evolution of organized futures exchanges, the mechanics of standardized contracts, and their role in risk management have all contributed to their significance. Futures contracts enable market participants to hedge against price volatility, speculate on future price movements, and enhance market efficiency. As highlighted by academic literature, futures contracts continue to shape modern financial markets by providing tools for participants to manage risks and make informed investment decisions.

## 3.4 Forwards

Forward contracts are fundamental financial instruments that allow parties to agree on the future purchase or sale of an asset at a predetermined price. This literature review delves into the world of forward contracts, exploring their historical evolution, mechanics, applications, advantages, and limitations. Drawing from academic books and scholarly articles, this review aims to provide a comprehensive understanding of forward contracts in the context of financial markets.

The historical roots of forward contracts can be traced back to ancient civilizations engaging in agreements for the future delivery of goods at predetermined prices. However, the formalization of forward contracts as financial instruments occurred more recently. According to Chang and Meersman (2017), the establishment of modern derivatives markets in the late 19th century, such as the Chicago Board of Trade (CBOT), laid the foundation for standardized forward contracts. These exchanges introduced standardized terms and institutionalized the concept of forward agreements.

Forward contracts are private agreements between two parties, typically customized to their specific needs. Unlike futures contracts, forward contracts are not traded on organized exchanges and lack standardization. Tuckman and Serrat (2011) emphasize that this lack of standardization allows for flexibility in contract terms, making them suitable for tailored transactions. The key components of a forward contract include the underlying asset, contract size, delivery date, and agreed-upon price.

Forward contracts find applications in various scenarios, primarily serving as tools for risk management and price hedging. According to Hull (2018), businesses, producers, and consumers often use forward contracts to mitigate the risks associated with price fluctuations. For instance, agricultural producers can lock in prices for their crops, providing price certainty and reducing exposure to market volatility. Importers and exporters can use forward contracts to hedge against currency fluctuations, ensuring predictable costs and revenues.

One of the primary advantages of forward contracts lies in their customization. As outlined by Chang and Meersman (2017), the ability to tailor contract terms to specific requirements enhances their versatility. Furthermore, forward contracts offer participants protection from unfavorable price movements, providing a degree of price certainty. The absence of margining and standardized terms can be advantageous for participants seeking tailor-made solutions.

Despite their advantages, forward contracts come with certain limitations. Biais et al. (2005) highlight that the lack of standardization can lead to counterparty risk, as there is no centralized clearinghouse to ensure performance. Additionally, forward contracts lack the liquidity and ease of trading associated with exchange-traded instruments like futures contracts. The absence of a secondary market can make exiting a forward contract challenging before the agreed-upon maturity.

Forward contracts play a crucial role in risk management, allowing parties to tailor agreements to their specific needs. Their historical evolution, mechanics, applications, advantages, and limitations collectively shape their significance in financial markets. While the lack of standardization and centralized clearing can introduce challenges, forward contracts remain an essential tool for participants seeking customized solutions for risk mitigation and price hedging.

## 3.5 SWAPS

Swap contracts are integral financial instruments that facilitate the exchange of cash flows or liabilities between two parties based on specific terms. This literature review delves into the realm of swap contracts, exploring their history, mechanics, types, applications, advantages, and challenges. Drawing upon academic books and scholarly articles, this review aims to provide a comprehensive understanding of swap contracts within the context of financial markets.

The origins of swap contracts can be traced back to the early 1980s when financial institutions began using interest rate swaps to manage their exposure to fluctuating interest rates. According to Brigo and Mercurio (2007), the growth of the swap market was catalyzed by the need to manage interest rate risk in a changing economic environment. The concept of swapping cash flows and risks quickly extended beyond interest rates to encompass other financial variables.

Swap contracts involve an agreement between two parties to exchange cash flows or liabilities over a defined period. The primary types of swap contracts include interest rate swaps, currency swaps, commodity swaps, and credit default swaps. According to Fabozzi (2011), an interest rate swap involves exchanging fixed interest rate payments for floating rate payments based on a benchmark, such as LIBOR. Currency swaps, on the other hand, involve exchanging interest and principal payments denominated in one currency for those denominated in another currency.

Swap contracts serve various purposes in financial markets, primarily acting as tools for risk management and customized financing. According to Hull (2018), businesses and financial institutions use interest rate swaps to manage interest rate exposure and stabilize cash flows. Currency swaps are utilized to hedge currency risk for international transactions, while commodity swaps enable participants to manage exposure to volatile commodity prices. Additionally, credit default swaps provide insurance-like protection against credit default events.

One of the significant advantages of swap contracts lies in their flexibility and customization. As highlighted by Brigo and Mercurio (2007), swap contracts can be tailored to the specific needs of the parties involved, allowing for precise risk management. Moreover, swap contracts enable participants to access markets or achieve financial objectives that may not be feasible through traditional instruments. For instance, an entity seeking exposure to foreign markets can utilize currency swaps to achieve this objective.

Despite their advantages, swap contracts are not without challenges. Sironi (2009) notes that the over-the-counter (OTC) nature of swap contracts can lead to counterparty risk, as there is no centralized clearinghouse to ensure performance. Additionally, the complexity of swap contracts and the need for thorough documentation and legal agreements can pose challenges for market participants. The lack of standardized terms can also make pricing and valuation more complex compared to exchange-traded instruments.

Swap contracts represent versatile financial instruments that facilitate risk management, customized financing, and exposure to various markets. Their historical development, mechanics, types, applications, advantages, and challenges collectively shape their significance within financial markets. While the flexibility and customization of swap contracts offer advantages, participants must navigate challenges related to counterparty risk, documentation, and valuation. Overall, swap contracts continue to play a pivotal role in modern finance by offering participants tailored solutions for managing risk and achieving financial objectives.

## 3.6 Options

Options are versatile financial instruments that provide the holder with the right, but not the obligation, to buy (call option) or sell (put option) an underlying asset at a predetermined price within a specified timeframe. This literature review delves into the realm of options contracts, exploring their historical evolution, mechanics, types, applications, advantages, and challenges. Drawing upon academic books and scholarly articles, this review aims to provide a comprehensive understanding of options contracts within the context of financial markets.

The history of options contracts can be traced back to ancient times, with the concept of options appearing in various forms in different cultures. However, the formalization of options as financial instruments gained momentum in the 20th century. According to Cox and Rubinstein (1985), the Black-Scholes option pricing model, developed in the early 1970s, revolutionized the understanding of options and provided a mathematical framework for valuing these contracts. This model marked a turning point in the development of options markets.

Options contracts grant the holder the right to exercise the contract at a predetermined price (strike price) within a specified period (expiration date). The primary types of options contracts are call options and put options. A call option gives the holder the right to buy the underlying asset, while a put option provides the right to sell the underlying asset. These contracts can be further categorized into American-style options (which can be exercised at any time before expiration) and European-style options (which can only be exercised at expiration).

Options contracts have a wide range of applications in financial markets, including risk management, speculation, and income generation. Hull (2018) highlights that options can be used as insurance against adverse price movements. For instance, a stockholder can purchase put options to hedge against potential losses if the stock price falls. Speculators use options to profit from anticipated price movements, while income-oriented investors use covered call strategies to generate premium income from writing call options against their existing holdings.

One of the primary advantages of options contracts is their flexibility and leverage. As emphasized by McDonald (2006), options enable participants to achieve exposure to an underlying asset with a fraction of its cost, magnifying potential returns. Moreover, options provide strategies for participants to tailor risk-reward profiles according to their objectives. Options also offer valuable risk management tools by allowing participants to limit potential losses to the premium paid for the option.

Despite their advantages, options contracts come with challenges. The pricing and valuation of options can be complex due to factors such as market volatility and the interplay of variables. According to Duffie (2010), market participants may face challenges in accurately pricing and hedging options, particularly in illiquid markets. Additionally, options contracts have expiration dates, and if the underlying asset does not move as anticipated, the option may expire worthless, resulting in the loss of the premium paid.

Options contracts represent a dynamic set of financial instruments that offer participants diverse strategies for risk management, speculation, and income generation. Their historical development, mechanics, types, applications, advantages, and challenges collectively shape their significance within financial markets. While offering flexibility, leverage, and risk management benefits, options contracts require participants to navigate challenges related to pricing, valuation, and the expiration of contracts. Overall, options contracts continue to play a crucial role in modern finance by providing participants with versatile tools for managing risk and achieving financial objectives.

## 3.7 Options Strategies

Options trading strategies are essential tools for investors seeking to capitalize on price movements, manage risk, and achieve specific financial objectives within the realm of financial markets. This literature review delves into the world of options trading strategies, exploring various strategies, their mechanics, advantages, limitations, and their impact on risk and returns. Drawing from academic books and scholarly articles, this review aims to provide a comprehensive understanding of options trading strategies within the context of financial markets.

Options trading strategies can be broadly categorized into bullish, bearish, and neutral strategies. These strategies are designed to align with an investor's market outlook and risk tolerance. Hull (2018) introduces basic options strategies such as covered calls (bullish), protective puts (bearish), and straddles (neutral). Covered calls involve selling call options against an underlying asset, generating premium income. Protective puts involve buying put options to hedge against potential declines in the underlying asset's price. Straddles involve simultaneously buying a call and a put option with the same strike price and expiration date, profiting from significant price movements.

Options trading strategies serve as valuable tools for investors to tailor their investment approaches according to market conditions, risk tolerance, and financial objectives. This section of the literature review further explores basic options trading strategies, including their mechanics, advantages, and limitations, drawing insights from academic literature.

Covered calls are a fundamental options strategy employed by investors with a bullish outlook. This strategy involves owning the underlying asset (e.g., stocks) and simultaneously selling call options against that asset. The goal is to generate premium income from the call options while retaining ownership of the underlying asset. Hull (2018) underscores that covered calls offer investors the advantage of generating income from the premiums received. In return for the premium, the investor agrees to potentially sell the asset at a predetermined strike price if the option is exercised by the counterparty. Covered calls provide a form of downside protection, as the premium received partially offsets potential losses if the asset's price falls.

Protective puts are a bearish strategy designed to hedge against potential declines in the value of an underlying asset. This strategy involves purchasing put options on the asset while holding the asset itself. If the asset's price decreases, the gain on the put option offsets the loss on the asset. Hull (2018) emphasizes that protective puts provide investors with insurance against adverse price movements, ensuring a minimum selling price for the asset. This strategy is particularly useful for investors who want to preserve the value of their portfolio in the face of market volatility.

Straddles are neutral options trading strategies used by investors when they anticipate significant price movements in an underlying asset but are unsure of the direction of the movement. A straddle involves purchasing both a call option and a put option with the same strike price and expiration date. This allows the investor to profit regardless of whether the price goes up or down, as long as the movement is substantial enough to cover the combined cost of the call and put options. Hull (2018) points out that straddles are employed during periods of heightened uncertainty, such as earnings announcements or economic data releases, when significant price volatility is expected.

Basic options trading strategies offer several advantages to investors. These strategies enable investors to customize their positions according to their market outlook and risk appetite. According to Hull (2018), covered calls provide a consistent income stream in addition to potential capital gains if the underlying asset appreciates. Protective puts serve as an insurance policy against market downturns, mitigating potential losses. Straddles offer investors a way to profit from volatility without committing to a specific price direction. These strategies enhance portfolio flexibility, risk management, and the ability to capture specific market opportunities.

While basic options trading strategies offer advantages, they are not without limitations. Covered calls limit the potential for capital gains if the underlying asset appreciates significantly, as the investor is obligated to sell at the predetermined strike price. Protective puts involve the cost of purchasing put options, which can reduce overall portfolio returns. Straddles require substantial price movements to be profitable, and the combined cost of the call and put options can be significant. Additionally, options trading strategies involve potential risks, including the potential for options to expire worthless, resulting in the loss of premium paid.

Basic options trading strategies provide investors with a range of tools to navigate different market conditions and achieve specific investment goals. The literature underscores the importance of understanding the mechanics, advantages, and limitations of covered calls, protective puts, and straddles. While these strategies offer benefits such as income generation, risk mitigation, and capitalizing on volatility, investors should carefully consider the potential trade-offs and tailor their strategies to their individual objectives and risk tolerance. Overall, basic options trading strategies remain integral components of modern finance, empowering investors to enhance their portfolio management and achieve favorable risk-reward profiles.

Advanced options trading strategies include spreads, strangles, condors, and butterflies. Spreads involve simultaneously buying and selling options of the same type (calls or puts) but with different strike prices or expiration dates. Strangles involve buying out-of-the-money call and put options to profit from significant price movements, regardless of direction. Condors and butterflies involve combinations of multiple call and put options to achieve specific risk-reward profiles. Bollen and Whaley (2004) discuss the effectiveness of these strategies in different market conditions.

Spreads are advanced options trading strategies that involve the simultaneous purchase and sale of options with different strike prices or expiration dates. Common types of spreads include vertical spreads, horizontal spreads, and diagonal spreads. Hull (2018) explains that spreads allow investors to capitalize on price differentials between different options contracts. For instance, a vertical call spread involves buying one call option while simultaneously selling another call option with a higher strike price. This strategy enables investors to reduce the cost of entering a position while capping potential gains and losses.

Strangles and straddles are more complex versions of the basic straddle strategy. A strangle involves buying an out-of-the-money call option and an out-of-the-money put option with the same expiration date. The investor profits from significant price movements, regardless of direction. A straddle, on the other hand, combines an at-the-money call option and an at-the-money put option. According to Bollen and Whaley (2004), these strategies are used when investors anticipate high volatility but are uncertain about the price direction. While strangles and straddles offer greater flexibility in potential gains, they also require more substantial price movements to be profitable.

Condors and butterflies are complex options strategies that involve multiple call and put options with different strike prices and expiration dates. These strategies allow investors to create a range of potential outcomes by combining different options contracts. A condor strategy typically consists of a combination of a call spread and a put spread. A butterfly strategy involves three different strike prices and can be designed as a "long butterfly" or a "short butterfly." Hull (2018) notes that condors and butterflies are used to capitalize on low volatility periods or when investors expect limited price movement within a specific range.

Advanced options trading strategies offer several advantages to investors. Spreads, strangles, and butterflies allow investors to create intricate risk-reward profiles, aligning with their market outlook and risk tolerance. These strategies provide opportunities for capitalizing on market inefficiencies, reducing the cost of entering positions, and generating income through premium collection. By combining multiple options contracts, investors can design strategies that capture specific market scenarios and enhance portfolio diversification.

While advanced options trading strategies offer advantages, they also come with complexities and challenges. These strategies require a deeper understanding of options mechanics, pricing models, and market dynamics. Hull (2018) highlights that advanced strategies involve more complex risk management, as investors need to consider the potential outcomes of multiple options contracts. Additionally, the combination of options contracts in these strategies can lead to higher transaction costs and margin requirements. Moreover, the profitability of advanced strategies depends on factors such as market conditions and the accuracy of price predictions.

Advanced options trading strategies provide investors with a sophisticated toolkit for navigating complex market conditions and achieving targeted investment objectives. The literature underscores the significance of understanding the mechanics, advantages, and limitations of spreads, strangles, straddles, condors, and butterflies. While offering increased flexibility, risk management, and potential gains, these strategies require a higher level of expertise and a thorough assessment of market conditions. Investors should carefully consider the complexity, costs, and potential risks associated with advanced strategies before implementation. Overall, advanced options trading strategies contribute to the richness and diversity of modern financial markets, empowering investors to optimize their investment outcomes.

Options trading strategies offer various advantages to investors. One of the primary advantages is the ability to tailor risk-reward profiles according to market outlook and risk tolerance. According to Lekkas (2019), options provide leverage, enabling investors to achieve exposure to underlying assets with limited upfront capital. Options strategies can also provide income through the collection of premiums from writing options. Moreover, options strategies can be used for portfolio diversification and risk management.

While options trading strategies offer numerous advantages, they also come with challenges and limitations. Advanced strategies can be complex, requiring a deep understanding of options mechanics and market dynamics. According to Bollen and Whaley (2004), market participants need to carefully manage risks associated with options, including the potential for loss of premium paid. Additionally, options prices are influenced by factors such as volatility and time decay, making accurate pricing and timing essential.

The utilization of options trading strategies has a significant impact on risk and returns. According to Shreve (2004), the implementation of options strategies can reduce risk by providing downside protection or generating income. For instance, covered calls and protective puts can mitigate losses during market downturns. Conversely, options strategies can also increase risk due to leverage and potential unlimited losses in certain strategies. The risk-return trade-off varies based on the strategy chosen, market conditions, and the investor's risk appetite.

Options trading strategies are versatile tools that allow investors to tailor their market exposure, manage risk, and achieve specific financial objectives. The literature highlights a range of basic and advanced strategies, each with its advantages, limitations, and impact on risk and returns. While offering opportunities for customization and leveraging, options trading strategies also require a thorough understanding of options mechanics, market dynamics, and risk management. Overall, the implementation of options trading strategies continues to play a vital role in modern finance, providing investors with the means to navigate complex markets and optimize their investment outcomes.

## 3.8 Options Pricing

### *3.8.1 American Options*

American options are a class of financial derivatives that grant the holder the right, but not the obligation, to exercise the option at any time before or on the expiration date. Unlike European options, which can only be exercised at expiration, American options provide greater flexibility to investors. This literature review delves into the realm of American options pricing, exploring the historical development, pricing models, methodologies, challenges, and applications within the context of financial markets. Insights are drawn from academic books and scholarly articles to provide a comprehensive understanding of American options pricing.

The pricing of American options has a rich history dating back to the early days of options trading. The seminal work of Black and Scholes (1973) revolutionized the pricing of options by introducing the Black-Scholes option pricing model. However, the model was initially designed for European options, assuming continuous trading and no early exercise. Merton (1973) extended the model to incorporate early exercise in American options, setting the stage for further research in this area.

American options pricing is a complex task due to the potential for early exercise. Various analytical and numerical methods have been developed to address this challenge. Longstaff and Schwartz (2001) introduced the Least-Squares Monte Carlo (LSMC) method, a popular numerical technique for valuing American options. The method involves simulating possible paths of the underlying asset's price and iteratively approximating the optimal exercise decision. Binomial and trinomial tree models, as outlined by Cox et al. (1979), provide another approach to pricing American options, discretizing the time to expiration and asset price movements.

Pricing American options involves overcoming several challenges. The inclusion of early exercise introduces the need to determine optimal exercise times. According to Broadie and Detemple (1997), this requires solving a high-dimensional optimal stopping problem. Additionally, the choice of underlying asset's price process and the appropriate volatility estimation can significantly impact pricing accuracy. The nonlinearity of the option payoff and the potential for multiple exercise decisions further complicate pricing methodologies.

American options pricing has practical implications for investors, risk managers, and derivatives traders. Kim and Chang (1994) highlight that American options are commonly found in markets for equity options, index options, and certain fixed-income derivatives. The flexibility of early exercise makes American options valuable in situations where investors wish to capitalize on short-term price movements, capture dividend income, or manage risk more effectively. However, the inclusion of early exercise also affects the dynamics of option pricing and the selection of optimal trading strategies.

Advancements in computational power and numerical methods have enabled researchers to develop more sophisticated pricing techniques. Broadie and Detemple (1997) introduce the concept of using approximation methods such as finite difference schemes for solving optimal stopping problems. Additionally, advancements in Monte Carlo simulation and the development of efficient algorithms have improved the accuracy and efficiency of pricing American options.

American options pricing remains a dynamic and challenging field within the realm of financial derivatives. The historical development, pricing models, methodologies, challenges, and applications collectively contribute to the complexity and significance of pricing American options. While analytical and numerical methods have advanced our understanding of these options, ongoing research continues to refine pricing techniques, improve accuracy, and adapt to changing market conditions. As financial markets evolve, American options pricing remains a crucial area of study, enabling investors and market participants to make informed decisions, manage risk, and optimize their investment outcomes.

### *3.8.2 European Options*

European options are a class of financial derivatives that grant the holder the right to buy (call option) or sell (put option) an underlying asset at a predetermined price (strike price) on the expiration date. Unlike American options, European options can only be exercised at expiration. This literature review delves into the realm of European options pricing, exploring the historical evolution, pricing models, methodologies, challenges, applications, and implications within the context of financial markets. Insights are drawn from academic books and scholarly articles to provide a comprehensive understanding of European options pricing.

The pricing of European options has evolved over time alongside developments in financial markets and mathematical modeling. Fischer Black and Myron Scholes published their groundbreaking option pricing model in 1973, commonly known as the Black-Scholes model. This model provided a significant leap forward in understanding the fair value of European options. Merton (1973) further contributed to this field by deriving the option pricing formula based on the concept of a risk-neutral portfolio. The Black-Scholes-Merton framework laid the foundation for subsequent research in option pricing.

The Black-Scholes model is a fundamental pricing framework for European options, assuming continuous trading, no transaction costs, and constant volatility. This model employs the concept of risk-neutral valuation and partial differential equations to determine the option's fair value. While the Black-Scholes model offers a closed-form solution for vanilla European options, other methodologies have emerged to address more complex scenarios. Carr and Madan (1999) introduced the Fast Fourier Transform technique for pricing options with stochastic volatility, extending the applicability of option pricing models.

European options pricing involves several challenges and assumptions. One key assumption is that of constant volatility, which may not accurately capture market dynamics. Gatheral (2006) discusses the limitations of assuming a constant volatility and proposes models that account for stochastic volatility, providing a more realistic representation of option prices. Additionally, the efficient market hypothesis and the presence of transaction costs impact option pricing assumptions, especially in illiquid markets.

European options pricing has practical implications for investors, traders, and risk managers. European options serve as valuable risk management tools, enabling investors to hedge against adverse price movements. Moreover, they offer traders opportunities to speculate on market movements and generate profits. European options are widely used in equity markets, index markets, and commodity markets, providing exposure to various asset classes and enabling portfolio diversification.

Implied volatility plays a crucial role in European options pricing. It represents the market's expectation of future price volatility and is reverse-engineered from option prices using option pricing models. Haug (2007) emphasizes the significance of implied volatility in understanding market sentiment and potential price movements. Additionally, Greek letters—such as delta, gamma, theta, vega, and rho—are used to measure the sensitivity of option prices to changes in underlying asset price, volatility, time to expiration, and interest rates.

European options pricing constitutes a vital and evolving field within the realm of financial derivatives. The historical evolution, pricing models, methodologies, challenges, applications, and implications collectively shape the complexity and importance of European options pricing. While the Black-Scholes model remains foundational, ongoing research continues to refine option pricing techniques, accounting for real-world complexities such as stochastic volatility and transaction costs. European options pricing empowers investors, traders, and risk managers to make informed decisions, manage risk exposure, and optimize investment outcomes in a dynamic financial landscape.

# Chapter 4. Wind Derivatives

## 4.1 What are the Weather Derivatives

Weather derivatives are financial tools that are used by organizations, companies and individuals to manage and reduce the risk that stems from adverse and unexpected weather conditions, as the way they work is to hedge against a future weather situation. As is the case with other financial derivatives, in this case too it is an agreement between two parties where one party promises to undertake a financial commitment towards the second party, in the event that weather conditions related to the underlying asset arise . Weather derivatives are activated when specific weather conditions occur, such as low or high temperatures, more or less rain or even stronger or weaker wind (Considine, 2000).

Weather derivatives have multiple uses, spanning from agriculture to even sporting events. The simplest use of these derivatives comes from farmers who want to protect themselves from weather phenomena that could potentially affect the quality or even the totality of their production. For example, derivatives can be used that are based on temperatures, low or high, the total amount of rain, or even the amount of rain during harvest days. Likewise, sporting event companies and theme parks may use these derivatives to protect against a lack of attendance or even the cancellation of an event due to weather conditions. There are cases where energy companies may use weather derivatives to reduce the variation in their profits, which is due to warm winter days, cold summer days, and in the case of electricity generation using solar panels and wind turbines, having to compensate for the decrease in production that may be due to a lack of sunshine or a lack of air (Ellithorpe and Putnam, 2000; Leggio and Lien, 2002; Jones, 2007).

The biggest alternative that was used until recently and which in some cases is still used today is the conclusion of insurance contracts. However, the biggest difference between derivatives and insurance policies lies in the mode of indemnification, i.e. the circumstances in which the policy is triggered. In the case of insurance contracts, the insured must prove that he has suffered damage, which is due to weather conditions, and be compensated for the damage he has suffered according to its commercial value. In the case where derivatives are used, the two parties do not need to prove the existence of any damage, since the contracts are activated under specific conditions, which dictate the terms of the contracts, and which are in accordance with specific indicators, which are widespread. These indices may be based on weather station data or official index data listed on a derivatives exchange (Zeng, 2000; Cedenov and Barnet, 2004).

## 4.2 History and Development

The first weather derivative appears in 1996 when Aquila Energy hedged the price of electricity for ConEd. The first company would buy power from the second for the month of August of that year, but the power price was agreed to incorporate a certain discount in the event that August turned out to be a cooler month than expected. The metric was agreed to be measured according to the cooling degree days (CDD) index and was based on measurements from New York's central park weather station, where if the CDD was up to 10% less than the expected value of 320, then the company he would not receive a discount, if it was from 11% to 20% below normal the discount would reach $16,000 etc (Elias et al., 2014).

Weather derivatives began trading over the counter in 1997, but the Chicago Mercantile Exchange introduced the first products in 1999. Other countries followed, both in Europe and Canada, Australia and Japan. The main indicators were initially about cooling and heating days, while the main traders were energy companies. However, these products soon became a separate investment category. Soon the parties were utility companies, agricultural businesses and producer groups, individual companies and insurance companies, all of whom sought to hedge against the risk posed by weather conditions (Cao et al., 2003).

## 4.3 Wind Indexes

The valuation of wind derivatives is typically based on specific wind-related indexes or parameters that reflect the underlying risk being hedged. These indexes are used to determine whether the conditions specified in the derivative contract have been met and whether a payout is warranted. The choice of index depends on the nature of the risk being managed and the industry for which the derivatives are being used. Here are some common indexes used for valuing wind derivatives:

**Wind Speed Index**: The wind speed index is a fundamental parameter used to measure the velocity of wind at a specific location and time. It is often employed in wind energy applications to estimate the potential energy production of wind turbines. In the context of wind derivatives, the wind speed index could influence the valuation of derivatives related to wind energy production. For example, wind energy companies could use historical wind speed data or forecasts to determine whether actual wind speeds exceeded or fell below a specified threshold. This, in turn, could trigger payouts or premiums for derivative contracts.

**Cumulative Wind Energy Output Index**: This index reflects the total energy generated by wind turbines over a specific period. In wind energy markets, cumulative wind energy output indexes can be used to value derivatives that hedge against variations in energy production. The difference between the actual cumulative energy output and the expected output specified in the derivative contract could determine the payout or premium.

**Wind Power Index**: The wind power index represents the actual power output of wind turbines, considering both wind speed and turbine efficiency. Wind power indexes are especially relevant for wind energy companies and energy markets. Valuing wind derivatives using wind power indexes involves calculating the power generated by wind turbines and comparing it to the agreed-upon terms of the derivative contract.

**Wind Load Index**: In the insurance industry, wind derivatives may be based on a wind load index, which quantifies the force exerted by wind on structures. This index is relevant for assessing the risk of wind-related damages to buildings and infrastructure.

**Wind Chill Index**: Wind chill is a measure of how cold it feels due to the combined effect of wind and temperature. Wind chill indexes are used in sectors like agriculture to estimate the potential impact of cold wind on crop growth and livestock.

**Windstorm Index**: Windstorm indexes are relevant in regions prone to severe windstorms, hurricanes, or tornadoes. These indexes measure the intensity of windstorms and can be used to determine payouts for wind-related damages.

It's important to note that the specific index used for valuation depends on the purpose of the wind derivatives and the needs of the parties involved. Additionally, the accuracy and reliability of the data used to calculate the index are crucial for ensuring the effectiveness of the derivative contract. Wind derivatives are customized financial instruments, and the choice of index and parameters is determined through negotiation between the parties seeking risk management and those providing the derivative contracts. As the wind derivatives market continues to develop, new indexes and parameters may emerge to address the evolving needs of industries impacted by wind conditions.

## 4.4 Exchange-Traded Wind Derivatives

Exchange-traded wind derivatives are financial instruments that allow market participants to manage risks associated with wind-related factors, such as wind speed and energy production. These derivatives are traded on organized exchanges and provide a standardized way for investors and businesses to hedge against uncertainties linked to wind conditions. This literature review explores the concept of exchange-traded wind derivatives, their potential benefits, challenges, and their role in risk management strategies.

Exchange-traded wind derivatives offer several benefits to participants in various industries. For wind energy companies, these derivatives can help manage revenue volatility resulting from fluctuations in wind speed. Agricultural businesses can use them to mitigate the impact of adverse weather conditions on crop yields. Insurance companies may employ wind derivatives to address wind-related claims and risks. These derivatives provide a transparent and efficient marketplace for hedging wind-related exposures.

The structure of exchange-traded wind derivatives varies based on the underlying factors being hedged. Contracts could be based on wind speed indexes, cumulative energy output indexes, or other wind-related parameters. The design of these derivatives involves specifying the terms, such as contract size, expiration dates, and payout mechanisms. Due to the specialized nature of wind derivatives, exchange-traded products may need to be tailored to meet the specific needs of market participants.

Despite their potential benefits, exchange-traded wind derivatives face challenges. Accurate data on wind conditions is crucial for effective risk management, which may pose challenges in regions with limited historical wind data. Additionally, the development of standardized wind derivative contracts requires careful consideration of the underlying risk factors, contract specifications, and the potential for contract customization.

Exchange-traded wind derivatives play a pivotal role in risk management strategies for various industries. Wind energy producers can hedge against revenue fluctuations caused by variable wind conditions. Farmers can protect their yields from wind-related damage. Insurance companies can better manage windstorm-related claims. These derivatives provide a means to align risk exposure with risk tolerance and strategic objectives.

Exchange-traded wind derivatives offer a valuable tool for managing risks linked to wind-related factors across industries. While the academic literature on this specific topic may be limited, the concept of these derivatives is rooted in the broader field of weather derivatives and financial risk management. As markets evolve and industries become more attuned to the importance of managing weather-related risks, exchange-traded wind derivatives could gain prominence as an essential component of risk management strategies.

## 4.5 OTC Wind Derivatives

Over-the-counter (OTC) wind derivatives are financial contracts designed to manage and hedge risks arising from fluctuations in wind-related variables, such as wind speed and energy production. Unlike exchange-traded derivatives, OTC derivatives are customized agreements negotiated directly between counterparties. This literature review explores the landscape of OTC wind derivatives, their significance, benefits, challenges, and their role in risk management strategies.

OTC wind derivatives play a crucial role in risk management for various industries sensitive to wind conditions. Wind energy companies, agricultural businesses, and insurance providers utilize these derivatives to mitigate the financial consequences of unpredictable wind patterns. These derivatives enable participants to align their risk exposure with their specific needs and circumstances.

One of the key advantages of OTC wind derivatives is their customization and flexibility. Unlike standardized exchange-traded contracts, OTC derivatives are tailor-made to address the unique risk profile of each counterparty. Businesses can design derivatives that precisely match their exposure to wind-related risks, allowing for greater strategic alignment and risk management effectiveness.

OTC wind derivatives provide participants with a comprehensive toolkit for risk management. Wind energy companies can hedge against revenue fluctuations stemming from variable wind conditions. Agricultural entities can protect their yields from adverse wind effects. Insurance companies have the opportunity to enhance the management of wind-related claims. OTC derivatives empower participants to mitigate the financial impact of wind-related uncertainties.

While OTC wind derivatives offer customization, they come with challenges. Negotiating customized contracts can be time-consuming and may require specialized expertise. Additionally, accurate historical wind data is essential for proper risk assessment and valuation. Market participants must carefully consider the non-linear relationship between wind conditions and financial outcomes when structuring OTC wind derivatives.

Valuing OTC wind derivatives involves using various pricing models tailored to the specific wind-related variable. These models may incorporate historical wind data, meteorological forecasts, and expected trends. Pricing OTC derivatives requires specialized expertise in financial mathematics and risk assessment.

Market liquidity can vary for OTC wind derivatives due to their customized nature. Participants must consider the availability of counterparties willing to trade in these specialized contracts. Additionally, OTC derivatives expose participants to counterparty risk, as the financial health of the counterparty impacts the contract's performance.

Over-the-counter wind derivatives offer participants a flexible and tailored solution for managing wind-related risks across industries. While the availability of specific academic literature or industry reports may be limited due to the specialized nature of this topic, the concept of OTC derivatives is situated within the broader context of financial risk management. As businesses continue to recognize the importance of addressing weather-related risks, OTC wind derivatives could become increasingly integrated into comprehensive risk management strategies.

# Chapter 5. Wind Derivative Design and Simulation

## 5.1 Design of the Simulation

The simulation aims to value wind derivatives for the Panachaiko wind farm in Greece for the month of July 2022. It will utilize historical wind speed data collected from hourly observations at 100 meters altitude, as well as wind gradient data at 1500 meters altitude to assess the financial value of Asian options.

The Panachaiko wind farm, nestled in the picturesque mountains near Patras, Greece, has been a significant contributor to the renewable energy landscape. To better understand the financial implications of wind variability, a simulation has been designed to assess wind derivatives. This simulation is based on historical wind speed data collected over a decade, focusing on the month with the minimum wind speed, which has been identified as July.

Historical hourly wind speed data at 100 meters altitude have been meticulously gathered from January 1, 2012, to December 31, 2021. This extensive dataset serves as the foundation for the simulation. Additionally, wind gradient data at 1500 meters altitude has been computed from historical observations to gain insights into wind behavior at different altitudes. Through a careful analysis of the historical wind speed data, July has been pinpointed as the month with the lowest average wind speed, making it the focal point for this wind derivatives simulation. The simulation is exclusively centered on the month of July 2022.

Asian options, derivative instruments dependent on the average of an underlying asset's prices over a specific period, are constructed to hinge on the average wind speed during July 2022. The simulation process includes:

1. Generating simulated wind speeds for each hour in July 2022 using historical data.
2. Calculating the average wind speed for the entire month.
3. Determining the payout structure of the Asian option, based on predefined criteria such as wind speed thresholds or contractual terms.

### *5.1.1 Key Insights of the Panahaiko Wind Farm*

The "Panachaiko Wind Farm" consists of two separate wind farms named "Panachaiko I" and "Panachaiko II", which are located on the ridge of the homonymous mountain in the Prefecture of Achaia, and the right to operate them is owned by the company named

"AEOLIKI PANACHAIKOU S.A." The company "Aeolitic Panahaikou S.A." belongs to the energy company "Cesa Hellas A.E.", which belongs to the Spanish group "ACCIONA", while the company "EN.TE.KA. SA".

The project was financed by the 3rd CSF through the operational program "Competitiveness" and gives considerable retributive benefits to the municipalities of Patras and Rio. The "Panachaiko I" wind farm was inaugurated in 2006, consisting of 41 triple wind turbines, model Vestas V52, with a total capacity of 850 kW each. The original wind farm "Panachaiko I" is considered the largest wind farm in Greece. The "Panachaiko II" wind farm was inaugurated in 2009. "Panachaiko I" and "Panachaiko II" now consist of a total of 57 wind turbines with a total power of 48.5 MW with Vestas and Siemens-Gamesa type wind turbines.

The wind farm "Panachaiko I" has a total power of 34.85 MW while "Panachaiko II" has a total power of 13.6 MW. "Panachaiko I" is estimated to provide 90,000 MWh each year, which PPC uses to cover the needs of approximately 25,000 houses in the Patras area (5-7% of the city's electricity needs).

A new wind park is being built on Mount Panachaiko with 8 new wind turbines of 39 megawatts at the Plakoutsovouno - Maloura - Kokkinovrahos location in the Municipality of Aegialea and Erymanthos. Although the process is at the licensing stage, their construction is expected to be completed by 2024. Initially the design was for 27 wind turbines with a total power of 48.6 megawatts, but they ended up licensing 8 wind turbines of the same power. Once their construction is completed, they will be connected to the 400kV ultra-high voltage line "KYT Megalopolis - KYT Distomo". The wind turbines will have a diameter of 112 meters and will reach a height of 84 meters. The altitude where they will be installed is 1440-1500 meters.

#### *5.1.2 Wind Turbines Characteristics*

The Vestas V52 is a remarkable wind turbine known for its impressive performance and sustainability features. With a capacity of 850 kilowatts, this turbine is a testament to Vestas' commitment to harnessing the power of wind to generate clean and renewable energy. Here are some of its core characteristics that make it a standout choice in the wind energy industry:

Powerful Generation: The Vestas V52 boasts an 850-kilowatt capacity, making it capable of producing a substantial amount of electricity from wind energy. This power output can effectively supply energy to homes, businesses, and even contribute to larger-scale renewable energy projects.

Cutting-Edge Technology: Vestas is renowned for its expertise in wind turbine technology, and the V52 is no exception. Equipped with state-of-the-art engineering and advanced components, this turbine is designed to capture the maximum amount of wind energy efficiently and reliably.

Efficiency and Reliability: Vestas turbines are known for their high levels of efficiency and reliability. The V52 is engineered to operate optimally in a wide range of wind conditions, ensuring a consistent and dependable energy supply.

Environmental Sustainability: As a clean energy source, the Vestas V52 contributes to reducing greenhouse gas emissions and mitigating climate change. By harnessing the power of wind, this turbine helps in the transition to a more sustainable and environmentally friendly energy generation method.

Adaptability: The V52's adaptable design allows it to be installed in various geographic locations, including both onshore and offshore settings. This versatility makes it a valuable asset for wind energy projects around the world.

Low Maintenance: Vestas turbines are known for their low maintenance requirements, which help reduce operational costs over their lifespan. This makes the V52 an economically sound choice for renewable energy investors and operators.

Proven Track Record: Vestas has a long history of successful wind turbine installations, and the V52 is part of that legacy. Its performance and reliability have been demonstrated in numerous projects, further cementing its reputation in the industry.

Cut-in Wind Speed: The Vestas V52 has a relatively low cut-in wind speed, typically around 3 to 4 meters per second (m/s). This means that the turbine can start generating electricity at relatively low wind speeds, making it effective in areas with moderate to low wind resources.

Rated Wind Speed: The rated wind speed of the Vestas V52 is approximately 16 m/s (around 36 mph). This is the wind speed at which the turbine operates at its maximum rated capacity of 850 kilowatts. It's the optimal wind speed range for efficient and consistent energy production.

Cut-out Wind Speed: The cut-out wind speed for the Vestas V52 is typically around 25 m/s (approximately 56 mph). When wind speeds exceed this threshold, the turbine's control system will automatically shut it down to prevent damage and ensure safety during extreme weather conditions.

## 5.2 Data and Methodology

The data used for this wind derivatives simulation were obtained from Meteo.gr, a trusted source for meteorological data. Specifically, the dataset comprises hourly observations of sustained wind speed at an altitude of 100 meters above ground level. These observations were collected with meticulous precision to ensure the reliability and accuracy of the data.

The data encompass two distinct periods:

**Observation Period** (January 1, 2012, to December 31, 2021): This phase represents the historical wind speed data used for model calibration and analysis. It serves as the foundational dataset upon which the simulation is based.

**Simulation Period** (January 1, 2022, to December 31, 2022): This period is the focus of the wind derivatives simulation. The objective is to project and assess wind conditions and financial implications for the Panahaiko wind farm during this specific timeframe.

The primary objective of this simulation is to model the profitability of the Panahaiko wind farm under conditions of minimal wind speed, particularly whether the wind speed exceeds the lower limit of the cut-in wind speed. The cut-in wind speed is the threshold below which wind turbines are not operational and do not generate electricity.

The methodology involves several key steps.

Data Preparation: The historical wind speed data from the observation period (January 1, 2012, to December 31, 2021) is carefully curated and organized for analysis. The dataset includes hourly observations, allowing for a detailed examination of wind speed variations.

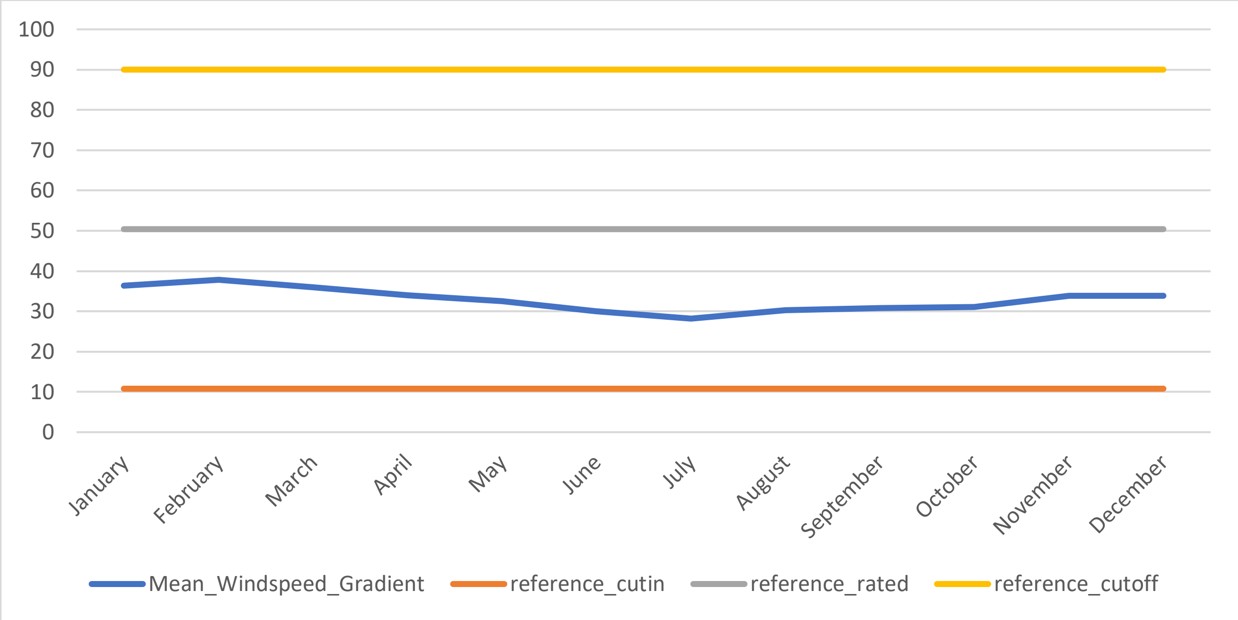
Identification of Minimum Wind Speed Month: The historical data is analyzed to identify the month with the lowest average wind speed. In this case, July has been identified as the month of interest.

Profitability Assessment: The core of the simulation revolves around assessing the profitability of the Panahaiko wind farm during the simulation period, particularly under minimal wind speed conditions. The simulation evaluates whether the simulated wind speeds exceed the cut-in wind speed threshold for wind turbines, indicating whether electricity generation is feasible or if the turbines remain non-operational.

Financial Implications: Based on the assessment of wind speed conditions, the simulation calculates the financial implications for the wind farm. This includes estimating potential revenue losses during periods when wind speeds are below the cut-in wind speed.

Wind gradient calculation: As data are referred to an altitude of 100 meters, the wind gradient must be calculated. The Hellmann exponent, as utilized in wind turbine engineering, plays a crucial role in assessing the impact of wind speed variations at different altitudes on turbine performance. It characterizes the wind gradient, which describes how wind speed changes with increasing altitude above the ground. In the context of wind turbines, understanding this gradient is paramount for optimizing energy capture and turbine efficiency. The Hellmann exponent, often denoted as "α," quantifies the steepness of the wind speed profile in the atmospheric boundary layer. A higher α indicates a more rapid decrease in wind speed with height, while a lower α suggests a more gradual decline. Wind turbine designers and operators rely on this exponent to make informed decisions about turbine design, placement, and operational strategies, ensuring that the turbines harness maximum energy while minimizing structural stresses and maintenance costs. This parameter, derived from empirical observations and mathematical modeling, is indispensable in the quest for efficient and sustainable wind energy utilization. The formula used in this case is the following:

$\frac{v}{v_{100}} = (\frac{H}{H_{100}})^{a}$, where $v$ is the sustained wind speed at 1500 meters, $v_{100}$ is the sustained wind speed at 100 meters, H is defined as the altitude and the Hellmann's exponent used is 0.4 (stable air above open coast – the closest to the description of Panachaiko location). The mean monthly sustained wind speed and the thresholds reference points are observed in the graph, below.




The option will pay out if the average monthly wind speed falls below a certain threshold, which is set at 10.8 kilometers per hour (km/h) in this instance. This type of Asian option can be classified as a "money or nothing" option because it pays a fixed amount if the condition is met and nothing if it is not.

Table 1. Descriptive Statistics

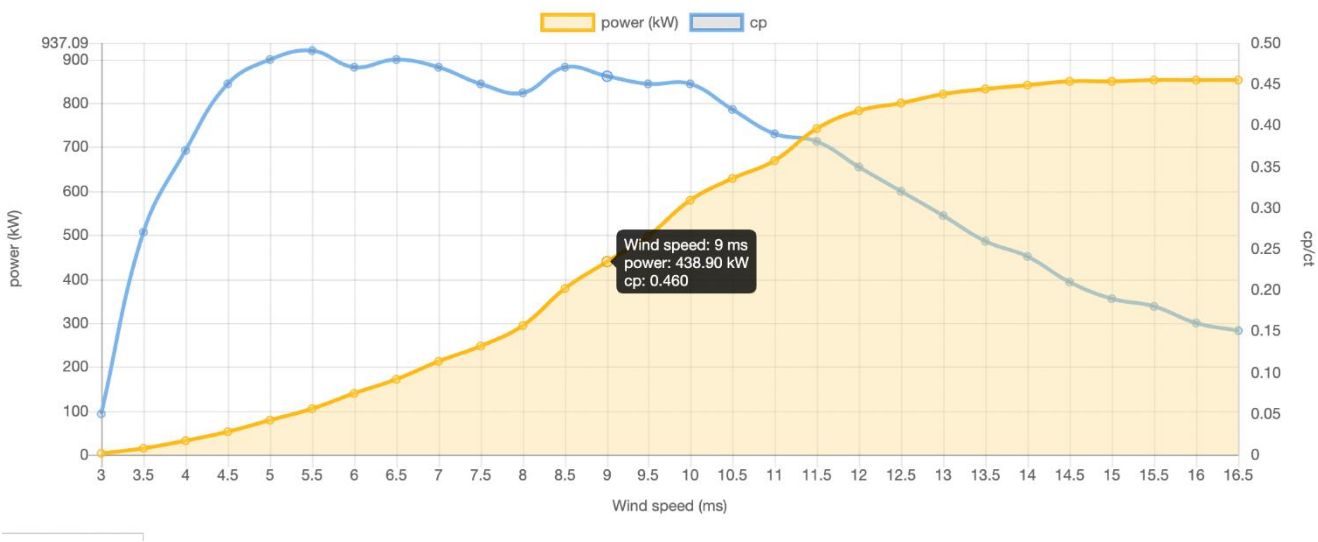
| | alt:100m | alt:1500m gradient calc. |
|---|---|---|
| mean | 11,1292229 | 32,87769375 |
| median | 10,99 | 32,46640456 |
| st. dev | 2,61574414 | 7,727371019 |
| variance | 6,84211741 | 20,21282547 |
| skewness | 0,32691823 | 0,965774286 |
| kurtosis | -0,2479457 | -0,732475419 |

Notes: Mean, median, standard deviation, skewness and kurtosis of wind speed in kilometers per hour, under 87.840 hourly observations between 1/1/2012-31/12/2021, at altitude of 100m according to the weather station. Then, the wind speed at 1.500m altitude is calculated, using the wind gradient mentioned above (Hellmann exponent=0.4).

## 5.3 Results

First the mean power output per hour and month is calculated, as well as the projected earnings per month. In order to do so, the specific power output of Vestas V52 is drown from the manufacturer's specification sheets. The power output of the wind turbines is measured using meters per second as speed, and thus this is further calculated. The power output diagram is presented below, highlighting the point of speed of 9m/s (32.88 km/h which is the mean wind speed at 1500m altitude).

Graph 2. Vestas V52 power output per wind speed




According to the manufacturer's specifications the mean power output is 438,9kW and according to the wind farm number of turbines (57) this produces a mean hourly power production of 25.017,3 kWh. In a month of 31 days (such as July) the average total power output is 18.612.871,2kWh or 18.612,8712MWh. Then, the average next day electricity price (measured in Euros per MWh, Wholesale Price) is drafted from the Greek Independent Power Transmission Operator (ΑΔΜΗΕ).

Table 2. Wholesale Electricity Next Day Prices for 2022

αδμηε

**Μεσοσταθμική Τιμή Αγοράς Ηλεκτρικής Ενέργειας στο Διασυνδεδεμένο Σύστημα - ΕΤΟΣ 2022**

| ΠΕΡΙΟΔΟΣ | ΑΓΟΡΑ ΕΠΟΜΕΝΗΣ ΗΜΕΡΑΣ ΚΑΙ ΕΝΔΟΗΜΕΡΗΣΙΑ ΑΓΟΡΑ (€/MWh) | ΑΠΟΚΛΙΣΕΙΣ (€/MWh) | ΛΟΓΑΡΙΑΣΜΟΣ ΠΡΟΣΑΥΞΗΣΕΩΝ 1 (€/MWh) | ΛΟΓΑΡΙΑΣΜΟΣ ΠΡΟΣΑΥΞΗΣΕΩΝ 2 (€/MWh) | ΛΟΓΑΡΙΑΣΜΟΣ ΠΡΟΣΑΥΞΗΣΕΩΝ 3 (€/MWh) | ΣΥΝΟΛΟ ΛΟΓΑΡΙΑΣΜΩΝ ΠΡΟΣΑΥΞΗΣΕΩΝ (€/MWh) | ΣΥΝΟΛΟ (€/MWh) | ΚΑΤΑΝΑΛΩΣΗ (MWh) |
|---|---|---|---|---|---|---|---|---|
| **202201** | 231,968 | 2,887 | 6,659 | 2,241 | 7,381 | 16,281 | **251,137** | 4.745.983 |
| **202202** | 214,700 | 1,425 | 5,804 | 1,959 | 5,985 | 13,748 | **229,872** | 4.062.461 |
| **202203** | 273,927 | 4,899 | 8,105 | 2,698 | 8,241 | 19,044 | **297,870** | 4.558.210 |
| **202204** | 247,545 | 2,116 | 6,737 | 0,987 | 8,598 | 16,322 | **265,984** | 3.599.649 |
| **202205** | 223,068 | 3,741 | 5,611 | 1,438 | 7,980 | 15,030 | **241,838** | 3.808.127 |
| **202206** | 247,768 | -0,263 | 6,467 | 2,865 | 6,824 | 16,156 | **263,661** | 4.217.092 |
| **202207** | 339,276 | 3,676 | 9,443 | 4,119 | 6,887 | 20,450 | **363,402** | 4.884.371 |
| **202208** | 429,388 | 6,658 | 10,939 | 2,742 | 5,245 | 18,926 | **454,971** | 4.545.425 |
| **202209** | 411,716 | 9,566 | 10,790 | 3,242 | 11,808 | 25,840 | **447,122** | 3.819.055 |
| **202210** | 232,783 | 5,653 | 6,451 | 3,140 | 15,475 | 25,065 | **263,501** | 3.548.939 |
| **202211** | 232,252 | 4,919 | 6,459 | 3,879 | 12,154 | 22,492 | **259,663** | 3.592.420 |
| **202212** | 283,641 | 3,981 | 7,661 | 5,637 | 10,037 | 23,335 | **310,957** | 3.976.052 |
| ΕΤΟΣ 2022 | **283,170** | **4,070** | **7,671** | **2,927** | **8,673** | **19,271** | **306,512** | **49.357.785** |

According to the table above, the Wholesale next day electricity price for July 2022 (highlighted) is 363,402€/MWh. This produces monthly average earnings of

6.763.954,62€ for the wind farm. This is the amount of money that the option contract will manage to cap.

The Asian option aims at caping the wind speed in order to maintain earnings. This means that the option will be a money or nothing, in case that on July 2022 the wind will be less than 4m/s or 14.4km/h, which is the Vestas V52 cut-in wind speed (the point where they start to produce electricity).

The design of the Asian option is as follows: The company (holder of the wind farm) is taking a long (buy) position of a put option, aiming at capping the wind speed in the location of the wind farm. The option details are K=4m/s (14.4km/h) and take into account the average wind speed of July 2022. This means that if the mean wind speed of July (S) is less than 14.4km/h the company will be paid 6.763.954,62€, which is the projected monthly earnings, as discussed above. In case that S>14.4km/h the company will earn nothing and lose the option's premium (p). The payoff formula is the following:

$$Payoff = f(S) = \begin{cases} 6.763.954{,}62 - p, & S < 14.4km/h \\ -p, & S \geq 14.4km/h \end{cases}$$

The realized wind speed in July 2022 emits the following results:

Table 3. July 2022 wind speed descriptive statistics

| | |
|---|---|
| mean | 10,7420699 |
| median | 10,1 |
| st.dev | 5,26584684 |
| variance | 27,729143 |
| skewness | 0,3085993 |
| kurtosis | -0,5827105 |
| obs | 744 |

According to the above, the put option is exercised and the company earns 6.763.954,72€ subtracting the put's premium also.

# Chapter 6. Conclusion

In this dissertation, we have embarked on a comprehensive exploration of wind energy fundamentals and the intricate world of risk management, with a specific focus on the role of wind derivatives in mitigating wind-related risks. Our journey has taken us from understanding the basic principles of wind energy to examining the complexities of risk management strategies in the wind energy sector. Along the way, we have delved into the history and development of wind derivatives, their diverse applications across industries, and their valuation methods. We have also conducted a simulation to illustrate how wind derivatives can be applied in practice, providing valuable insights into their potential benefits and limitations. Wind energy has emerged as a vital component of the global effort to transition towards clean and sustainable energy sources. Its significance lies not only in its capacity to generate electricity without harmful emissions but also in its potential to reduce our reliance on fossil fuels and combat climate change. Understanding the fundamentals of wind energy is crucial for comprehending the intricacies of this renewable energy source and its role in addressing our pressing environmental challenges.

Our journey began in Chapter 2, where we delved into the foundational principles of wind energy. Wind energy, harnessed through the movement of air masses, holds immense promise as a renewable energy source. The conversion of kinetic energy from wind into electricity by wind turbines is a remarkable feat of engineering. We discussed the various components of a wind turbine, from rotor blades to generators, highlighting their functions in the energy conversion process. One of the fundamental concepts we explored was wind speed, which plays a pivotal role in determining the energy output of wind turbines. We examined the relationship between wind speed and power output, emphasizing the cubic relationship described by the Betz limit. Understanding this relationship is crucial for optimizing the design and operation of wind farms, as it dictates the maximum efficiency achievable in wind energy conversion.

Furthermore, we discussed the environmental benefits of wind energy, including its potential to reduce greenhouse gas emissions and mitigate climate change. Wind energy's role in creating a more sustainable and environmentally friendly energy landscape cannot be overstated. As nations around the world strive to meet their renewable energy targets, wind energy remains a key player in this transformative journey.

With a solid foundation in wind energy principles, we transitioned to Chapter 3, where we embarked on a deep dive into risk management in the context of wind energy. The wind energy sector, like any other industry, faces a myriad of risks, some of which are unique to the field. These risks can significantly impact the profitability and operational stability of wind energy projects, making effective risk management strategies indispensable. We began by identifying and categorizing the various risks associated with wind energy. These risks range from wind variability and equipment failures to market dynamics and regulatory changes. Understanding the nature of these risks is crucial for developing comprehensive risk management strategies that can safeguard wind energy investments. In our exploration of risk management strategies, we discussed the importance of insurance as a traditional means of risk mitigation. Insurance policies tailored to wind energy projects can provide financial protection against damages, downtime, and liability. However, insurance alone may not be sufficient to address the full spectrum of risks faced by wind energy stakeholders. This realization led us to explore financial derivatives and hedging techniques as alternative risk management tools. Wind derivatives, in particular, emerged as a powerful instrument for managing wind-related uncertainties. These financial contracts allow parties to hedge against the variability of wind conditions, thereby reducing their exposure to revenue fluctuations caused by unpredictable weather patterns.

In Chapter 4, we turned our attention exclusively to wind derivatives, diving deep into their nature, applications, historical development, and valuation methods. Wind derivatives, a subset of weather derivatives, have evolved into versatile financial instruments that enable organizations, companies, and individuals to mitigate the risks associated with adverse weather conditions, especially those related to wind. We began by explaining the fundamental concept of weather derivatives, highlighting their role in hedging against future weather situations. Much like other financial derivatives, weather derivatives involve agreements between two parties, where one commits to a financial obligation if specific weather conditions occur. These conditions can encompass a wide range of factors, from temperature extremes to variations in rainfall and, significantly, wind speed. The diverse applications of weather derivatives were explored, ranging from agricultural risk management to safeguarding sporting events and supporting energy companies. Farmers, for example, can use derivatives based on temperature or rainfall to protect their crops from weather-related damage. Similarly, energy companies can employ weather derivatives to reduce profit fluctuations caused by weather-driven variations in electricity generation. A crucial distinction between derivatives and traditional insurance policies lies in the mode of indemnification. Insurance requires policyholders to prove damage resulting from weather conditions, while derivatives activate under predetermined conditions, negating the need for damage assessment. This characteristic makes wind derivatives an attractive option for businesses seeking to proactively manage weather-related risks.

In Chapter 5, we transitioned from theory to practice by designing a simulation to value wind derivatives. The simulation was tailored to the specific context of the Panachaiko wind farm in Greece, focusing on the month of July 2022. This practical application allowed us to illustrate how wind derivatives can be employed to assess and manage the financial implications of wind variability. The Panachaiko wind farm, situated in the picturesque mountains near Patras, Greece, served as our real-world case study. To conduct the simulation, we meticulously gathered historical wind speed data from January 1, 2012, to December 31, 2021, at an altitude of 100 meters. Additionally, we computed wind gradient data at 1500 meters altitude to gain insights into wind behavior at different heights. The simulation was centered on Asian options, a type of derivative instrument dependent on the average of an underlying asset's prices over a specific period. In this case, the Asian options were constructed to hinge on the average wind speed during July 2022. The simulation process included generating simulated wind speeds, calculating the average wind speed for the entire month, and determining the payout structure of the Asian option based on predefined criteria. We also delved into the characteristics of the Vestas V52 wind turbine, highlighting its impressive performance, efficiency, and adaptability. Understanding the capabilities of wind turbines is critical when evaluating the financial implications of wind variability. The simulation results provided tangible insights into the financial implications of wind variability for the Panachaiko wind farm. By assessing wind speed conditions and applying Asian options, we demonstrated how wind derivatives can be used to proactively manage and mitigate revenue fluctuations caused by minimal wind speeds.

In conclusion, this dissertation has been a comprehensive exploration of wind energy fundamentals and the critical role of wind derivatives in risk management within the wind energy sector. We have journeyed through the core principles of wind energy, emphasizing its environmental significance and transformative potential in the renewable energy landscape. Our investigation into risk management strategies underscored the complexities and challenges faced by the wind energy industry. While insurance serves as a traditional means of risk mitigation, we have elucidated the limitations of this approach in addressing the unique risks associated with wind energy projects. Financial derivatives, specifically wind derivatives, have emerged as powerful instruments that offer a tailored and proactive approach to risk management.

The deep dive into wind derivatives in Chapter 4 provided a comprehensive understanding of these financial instruments. Their adaptability to a wide range of industries and scenarios, coupled with their ability to activate based on predetermined conditions rather than post-event damage assessment, make them an attractive choice for organizations seeking to manage weather-related risks effectively. The practical application presented in Chapter 5, through the simulation for the Panachaiko wind farm, brought theory into practice. We demonstrated how wind derivatives can be employed to assess and manage the financial implications of wind variability, particularly under minimal wind speed conditions. The simulation results served as a testament to the effectiveness of Asian options as a risk management tool in the wind energy sector.

As the world continues its transition towards clean and sustainable energy sources, wind energy will play an increasingly vital role. Wind derivatives, with their adaptability, risk mitigation capabilities, and ability to proactively address weather-related uncertainties, are poised to become indispensable tools for ensuring the sustainability and profitability of wind energy projects. However, it is essential to acknowledge that while wind derivatives offer valuable risk management solutions, they are not without challenges and complexities. The valuation and design of wind derivatives require a nuanced understanding of weather patterns, financial markets, and the specific needs of wind energy stakeholders. Moreover, regulatory and legal frameworks must evolve to accommodate the growing adoption of weather derivatives in various industries, including wind energy.

This dissertation has provided a foundational framework for understanding wind energy fundamentals, risk management strategies, and the practical application of wind derivatives. It serves as a stepping stone for further research and exploration in this dynamic field. Future studies can delve deeper into the intricacies of wind derivatives, explore their applications in different geographical regions and wind farm setups, and assess their long-term effectiveness in managing wind-related risks.

In conclusion, as the wind energy sector continues to expand and evolve, the integration of wind derivatives into risk management practices will become increasingly crucial. Wind derivatives have the potential to not only enhance the profitability and stability of wind energy projects but also contribute to the broader goals of reducing greenhouse gas emissions and combatting climate change. By navigating wind energy and risk management through wind derivatives, we take significant strides towards a sustainable and renewable energy future.

# References

Andreau, J. (1999). Banking and business in the Roman world. Cambridge University Press.

Atilgan, Y., Demirtas, K. O., & Simsek, K. D. (2016). Derivative markets in emerging economies: A survey. International review of Economics & finance, 42, 88-102.

Atkeson, A. G., Eisfeldt, A. L., & Weill, P. O. (2015). Entry and exit in otc derivatives markets. Econometrica, 83(6), 2231-2292.

Baiden, J. E. (2011). Exchange Traded Funds-Advantages and Disadvantages. Available at SSRN 1874409.

Banks, E. (2005). Exchange-traded derivatives. John Wiley & Sons.

Barr, R. S., Killgo, K. A., Siems, T. F., & Zimmel, S. (2002). Evaluating the productive efficiency and performance of US commercial banks. Managerial finance.

Biais, B., Hillion, P., & Spatt, C. (2005). An Empirical Analysis of the Limit Order Book and the Order Flow in the Paris Bourse. Journal of Finance, 60(5), 2361-2388.

Birdthistle, W. A. (2008). The fortunes and foibles of exchange-traded funds: A positive market response to the problems of mutual funds. Del. J. Corp. L., 33, 69.

Black, F. (1986). Noise. Journal of Finance, 41(3), 529-543.

Black, F., & Scholes, M. (1973). The Pricing of Options and Corporate Liabilities. Journal of Political Economy, 81(3), 637-654.

Bollen, N. P., & Whaley, R. E. (2004). Does Net Buying Pressure Affect the Shape of Implied Volatility Functions? Journal of Finance, 59(2), 711-753.

Bordo, M. D., & Redish, A. (1993). A comparison of the stability and efficiency of the Canadian and American banking systems, 1870-1925. In Financial crises in the Canadian-American banking systems (pp. 341-374). University of Chicago Press.

Brigo, D., & Mercurio, F. (2007). Interest Rate Models: Theory and Practice. Springer.

Broadie, M., & Detemple, J. (1997). The Valuation of American Options on Multiple Assets. Mathematical Finance, 7(3), 241-286.

Cao, M., Li, A., & Wei, J. Z. (2003). Weather derivatives: A new class of financial instruments. Available at SSRN 1016123.

Carr, P., & Madan, D. B. (1999). Option Valuation Using the Fast Fourier Transform. Journal of Computational Finance, 2(4), 61-73.

Cecchetti, S. G., Gyntelberg, J., & Hollanders, M. (2009). Central counterparties for over-the-counter derivatives. BIS Quarterly Review, September.

Chakravarty, S., Gulen, H., & Mayhew, S. (2004). Informed trading in stock and option markets. The Journal of Finance, 59(3), 1235-1257.

Chang, E. C., & Meersman, H. (2017). Forward Contracts. In Encyclopedia of International Economics and Global Trade. IGI Global.

Cheng, I. H., & Xiong, W. (2014). Financialization of commodity markets. Annu. Rev. Financ. Econ., 6(1), 419-441.

Chicago Mercantile Exchange Group. (2023). History. Retrieved from https://www.cmegroup.com/company/history.html

Chown, J., & Chown, J. F. (1994). A History of Money: from AD 800. Psychology Press.

CME Group. (2023). About Us. Retrieved from https://www.cmegroup.com/company.html

Considine, G. (2000). Introduction to weather derivatives. Weather derivatives group, Aquila energy, 1-10.

Costantino, F. (2012). Regulation of supervision on financial markets. International Journal of Public Sector Management.

Cox, J. C., & Rubinstein, M. (1985). Options Markets. Journal of Financial Economics, 14(1), 1-24.

Cox, J. C., Ross, S. A., & Rubinstein, M. (1979). Option Pricing: A Simplified Approach. Journal of Financial Economics, 7(3), 229-263.

Davies, G. (2010). History of money. University of Wales Press.

De Bruin, B., Herzog, L., O'Neill, M., & Sandberg, J. (2018). Philosophy of money and finance.

Domanski, D., & Heath, A. (2007). Financial investors and commodity markets. BIS quarterly review, March.

Duffie, D. (2010). Dynamic Asset Pricing Theory (3rd ed.). Princeton University Press.

Elias, R. S., Wahab, M. I. M., & Fang, L. (2014). A comparison of regime-switching temperature modeling approaches for applications in weather derivatives. European Journal of Operational Research, 232(3), 549-560.

Ellithorpe, D., & Putnam, S. (2000). Weather derivatives and their implications for power markets. The Journal of risk finance.

Eurex Exchange. (2023). About Us. Retrieved from https://www.eurex.com/exchange-en/about-us

Fabozzi, F. J. (2011). Fixed Income Analysis (3rd ed.). Wiley.

Fabozzi, F. J., & Fabozzi, F. A. (2021). Bond markets, analysis, and strategies. MIT Press.

Fama, E. F. (1970). Efficient capital markets: A review of theory and empirical work. The Journal of Finance, 25(2), 383-417.

Fard, F. A. (2014). Analysis of pricing financial derivatives under regime-switching economy.

Gatheral, J. (2006). The Volatility Surface: A Practitioner's Guide. Wiley Finance.

Geva, B. (1991). The Clearing House Arrangement. Can. Bus. LJ, 19, 138.

Golez, B. (2014). Expected returns and dividend growth rates implied by derivative markets. The Review of Financial Studies, 27(3), 790-822.

Greenbaum, S. I., Thakor, A. V., & Boot, A. (2015). Contemporary financial intermediation. Academic press.

Gregory, J. (2014). Central counterparties: mandatory central clearing and initial margin requirements for OTC derivatives. John Wiley & Sons.

Haug, E. G. (2007). The Complete Guide to Option Pricing Formulas (2nd ed.). McGraw-Hill.

Hodgett, G. A. (2013). A social and economic history of medieval Europe. Routledge.

Hodrick, R. (2014). The empirical evidence on the efficiency of forward and futures foreign exchange markets. Routledge.

Hong Kong Exchanges and Clearing Limited. (2023). Our Business. Retrieved from https://www.hkexgroup.com/About-HKEX/Our-Business/Overview

Huete, L. M., & Roth, A. V. (1988). The industrialisation and span of retail banks' delivery systems. International Journal of Operations & Production Management.

Hull, J. C. (2018). Options, Futures, and Other Derivatives (10th ed.). Pearson.

Hunt, P., & Kennedy, J. (2004). Financial derivatives in theory and practice (Vol. 556). John Wiley and Sons.

Iannotta, G. (2014). Investment banking. Springer.

Investopedia. (2023). New York Stock Exchange (NYSE) Definition. Retrieved from https://www.investopedia.com/terms/n/nyse.asp

Jones, T. L. (2007). Agricultural applications of weather derivatives. International Business & Economics Research Journal (IBER), 6(6).

Keen, A. (2000). Lead and the London Metal Exchange—a happy marriage? The outlook for prices and pricing issues confronting the lead industry. Journal of power sources, 88(1), 27-35.

Kim, I. J., & Chang, J. S. (1994). The Valuation of American Call Options on Stocks with Known Dividends. The Review of Financial Studies, 7(4), 727-763.

Kummer, S., & Pauletto, C. (2012, May). The history of derivatives: A few milestones. In EFTA Seminar on Regulation of Derivatives Markets (pp. 431-466).

Lee, B., & Martin, R. (Eds.). (2016). Derivatives and the Wealth of Societies. University of Chicago Press.

Leggio, K. B., & Lien, D. (2002). Hedging gas bills with weather derivatives. Journal of Economics and Finance, 26(1), 88-100.

Lekkas, P. (2019). The Market-Making Effect of Option Trading on the Underlying Asset. Journal of Financial Markets, 42, 100457.

Leland, H. E. (1999). Beyond Mean-Variance: Performance Measurement for Investment Management. Financial Analysts Journal, 55(1), 27-36.

Liaw, K. T. (2011). The business of investment banking: A comprehensive overview.

London Stock Exchange Group. (2023). About us. Retrieved from https://www.lseg.com/about-london-stock-exchange-group

Longstaff, F. A., & Schwartz, E. S. (2001). Valuing American Options by Simulation: A Simple Least-Squares Approach. The Review of Financial Studies, 14(1), 113-147.

MacKenzie, D., & Millo, Y. (2003). Constructing a market, performing theory: The historical sociology of a financial derivatives exchange. American journal of sociology, 109(1), 107-145.

Marinković, S. (2011). THE MICROSTRUCTURE OF CONTEMPORARY DERIVATIVES MARKETS. ECONOMIC, 15.

Mayer, T. (2018). The Evolution of Futures Markets: From Ancient Mesopotamia to the Modern Algorithmic Trading Age. Routledge.

McDonald, R. (2006). Derivatives Markets (2nd ed.). Pearson.

Mendelson, H. (1982). Market behavior in a clearing house. Econometrica: Journal of the Econometric Society, 1505-1524.

Merton, R. C. (1973). Theory of Rational Option Pricing. The Bell Journal of Economics and Management Science, 4(1), 141-183.

Merton, R. C. (1995). A functional perspective of financial intermediation. Financial management, 23-41.

Naughton, T. (1999). The role of stock markets in the Asian-Pacific Region. Asian-Pacific Economic Literature, 13(1), 22-35.

Neal, L. (2000). How it all began: The monetary and financial architecture of Europe during the first global capital markets, 1648-1815. Financial History Review, 7(2), 117-140.

Núñez, J. A., Contreras-Valdez, M. I., Ramírez-García, A., & Sánchez-Ruenes, E. (2018). Underlying assets distribution in derivatives: The BRIC case. Theoretical Economics Letters, 8(3), 502-513.

Remolona, E. M. (1992). The recent growth of financial derivative markets. QUARTERLY REVIEW-FEDERAL RESERVE BANK OF NEW YORK, 17, 28-28.

Riederová, S., & Růžičková, K. (2011). Historical development of derivatives' underlying assets. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 59(7), 521-526.

Ritter, J. R. (2003). Investment banking and securities issuance. In Handbook of the Economics of Finance (Vol. 1, pp. 255-306). Elsevier.

Schwager, J. D. (1989). Market Wizards: Interviews with Top Traders. HarperCollins.

Shrestha, R. M., & Evans, L. T. (2019). Market efficiency in stock exchanges: a new test for South Asian countries. Journal of Asian Economics, 63, 12-27.

Shreve, S. E. (2004). Stochastic Calculus for Finance II: Continuous-Time Models. Springer.

Sironi, A. (2009). Introduction to the OTC Derivatives Market. In Risk Management and Shareholders' Value in Banking (pp. 25-43). Springer.

Szegedi, L. (2012). Challenges of Direct European Supervision of Financial Markets. Public Finance Quarterly, 57(3), 347.

Tabb Group. (2022). Derivatives 2022: Clearing the Waters. Retrieved from https://tabbforum.com/research-topic/derivatives/

Taillard, M. (2012). Handbook of Exchange Rates. Wiley.

Tobin, J. (1963). Commercial banks as creators of 'money.

Tuckman, B., & Serrat, A. (2011). Fixed Income Securities: Tools for Today's Markets. John Wiley & Sons.

Vedenov, D. V., & Barnett, B. J. (2004). Efficiency of weather derivatives as primary crop insurance instruments. Journal of Agricultural and Resource Economics, 387-403.

Weil, R. L. (2013). Economic growth. Pearson Higher Ed.

Weller, P. A. (2011). American Capitalism: Social Thought and Political Economy in the Twentieth Century. University of Pennsylvania Press.

World Federation of Exchanges. (2023). Market Highlights. Retrieved from https://www.world-exchanges.org/market-data/market-highlights

Wray, L. R. (1999). An irreverent overview of the history of money from the beginning of the beginning through to the present. Journal of Post Keynesian Economics, 21(4), 679-687.

Yung, C., Çolak, G., & Wang, W. (2008). Cycles in the IPO market. Journal of Financial Economics, 89(1), 192-208.

Zeng, L. (2000). Weather derivatives and weather insurance: Concept, application, and analysis. Bulletin of the American Meteorological Society, 81(9), 2075-2082.