FACULTY OF ECONOMICS AND
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ANALYSING THE EU WHOLESALE ELECTRICITY MARKET'S LONG-TERM PRICE RISK AND IMPLEMENTING CFDS AS A HEDGING TOOL

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Gaël Bogaert
Student number: 01804041

Supervisor: Prof. Dr. Marten Ovaere

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ABSTRACT

This master's dissertation identifies how long-term price-risk can be mitigated by developers in renewable energy sources through implementing contracts-for-difference on the European wholesale electricity market (EU WEM). Hereby, ensuring a stable revenue stream, to enable the acceleration of deployment of renewable energy installations in Europe in line with the policy objectives of the European Commission. Herewith, this thesis mainly departed from the approaches embedded within the literature of Schittekatte and Batlle (2023a), Newbery (2023) and Schlecht et al. (2023).

This research is particularly timely and relevant given the recent developments since the gas price shock resulting from the war between Ukraine and Russia and the subsequent statement made by Ursula von Der Leyen, urging for a redesign of the EU WEM. After analyzing the distortions derived from the current design of the EU WEM, the distortions derived from the traditional contract structure of the CfD were analyzed thoroughly. This elucidated the fact that setting a strike price through competitive auctioning, was the most efficient method as this drove down the costs of capital from the developers.

However, the design caused a distortive view of the intraday market due to the inefficient choice of a reference price period. Further, setting the hourly spot price derived from the day-ahead market as a reference price, causes the issue of produce and forget. This implies it incentivizes investors to maximize their output, ignoring herewith production at least-system cost, and risking potential hours of negative prices. In an attempt to mitigate this risk, by setting a longer reference price period, another distortion remained present, namely the influence of actual generated output of the generator on the payments disbursed by the CfD. Hereafter, multiple routes were explored brought forth by this literature review, trying to decouple the actual output from these payments. This ultimately led to proposing an auctioned contract design hedging against price and volume risk, by mitigating the distortions derived from its initial structure. This design consists of an annual reference price period with a strike price set through a competitive, technology-specific auction which awards the contracts through a highest-accepted-bid-method.

Although the solution lays within specific design choices for specific technologies, the assessment put the financial CfD by Schlecht et al. (2023) forward as the most optimal design in hedging the long-term price risk of intermittent renewable electricity. Consequently, the contract mitigates day-ahead-distortion (i.e., curtailing production during negative priced hours), intraday distortion, locational distortions, distorted decision-making regarding (retrofitting) investments and maintenance scheduling and volume risk, whether these distortions are stemming from weather conditions or not. Hereby the financial CfD ensures the most stable revenue stream for developers of renewable energy technologies at least-system cost, which supports the acceleration of the deployment of renewable energy in Europe. This is in line with the policy objectives outlined in the recent developments of the EU Commission's latest proposal on this subject.

Lastly, Chapter 4 analyzed the design structure of the Danish wind CfD and Spanish wind CfD. Hereby the most optimal design was the Spanish wind CfD as its focal point remains on embedding some merchant risk exposure within its structure. Moreover, the Danish CfD did not foresee such clause within its contract. This led to the investors seeking a way out of the agreement, by setting a significant low strike price to pay back the regulator for limited number of years. As a consequence, when the CfD was fulfilled, they could go merchant, freed from the CfD imposed on the project. On the contrary, the Danish CfD used an annual reference price period, while the Spanish CfD used hourly spot price rate. The latter option is herewith significantly more distortive than the former.

Within this master's dissertation, the focus remained on how the design of contracts-for-difference serves as a hedging tool for long-term price risk. This should incentivize electricity developers to rapidly invest in renewable energy generation, not only to evade the Russian gas dependency but also to achieve the sustainability objectives of the European Union and let consumers benefit from the low operational costs stemming from this "green" energy (European Commission, 2023b). Further, this thesis provides an academical supplement to the existing literature on the suggestions for an optimal CfD design made by various authors in the last couple of years. However, as the energy market is an ever-evolving research subject, new contract designs should be analyzed on a continuous pace in order to continue fulfilling the requirements of this market.

Keywords: contracts-for-difference, renewable energy resources, long-term price risk, climate policy, contract design, price distortion

FOREWORD

It is with great pleasure that I present this master's dissertation which lies before you. An academic endeavor that represents my unwavering curiosity for a research field that has rather be unknown to me prior to writing this thesis. Although this journey presented difficult challenges and the direction in which to go was not always clear, it led to expanding my personal and academic growth. Hereby, it is my hope that this work not only meets the requirements for which it was created but also serves as a valuable resource for future scholars and practitioners in the field. Lastly, I want to express my great appreciation for Prof. Dr. Marten Ovaere for providing me brightening insights and guiding me throughout the course of this work. Furthermore, a heartfelt thank you goes to my friends and family for providing me with their support when needed.

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LIST OF ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
BZ	Bidding Zone
CapEx	Capital Expenditures
CCPs	Central Clearing Counterparties
CfDs	Contracts for Difference
CoC	Cost of Capital
CPI	Consumer Price Index
D/E Ratio	Debt-to-Equity Ratio
DAM	Day-Ahead Market
DEA	Danish Energy Agency
DECC	Department of Energy & Climate Change
EMIR	European Market Infrastructure Regulation
EMR	Electricity Market Reform
ENTSO-E	European Network of Transmission System Operators for Electricity
EPEX	European Power Exchange
ETS	Emissions Trading System
FIDeR	Final Investment Decision Enabling for Renewables
FiTs	Feed-in Tariffs
IMF	International Monetary Fund
kWh	Kilowatt-hour
LCCC	Low Carbon Contracts Company
LCOE	Levelized Cost of Electricity
LMP	Locational Marginal Pricing
MWh	Megawatt-hour
NECPS	National Energy and Climate Plans
NG	National Grid
NPV	Net Present Value
OTC	Over-The-Counter

PPAs	Power Purchase Agreements
REA	Association for Renewable Energy & Clean Technologies
RES	Renewable Energy Sources
RES-E	Renewable Energy Source Electricity
RO	Renewable Obligation
RTM	Intraday or Real-Time Market
TP	Transparency Platform
TSO	Transmission System Operator
WACC	Weighted Average Cost of Capital
WEM	Wholesale Electricity Market

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1 INTRODUCTION

This dissertation, entitled "Analysing the EU Wholesale Electricity Market's Long-Term Price Risk and Implementing CfDs as a Hedging Tool," embarks on a critical exploration of the complexities and challenges within the design of the European Union's wholesale electricity market (WEM). The focus lays on understanding and mitigating the inherent long-term price risks through designing efficient Contracts-for-difference (CfD). This research is particularly timely and relevant given the recent developments since the gas price shock resulting from the war between Ukraine and Russia. The following statement of president of the EU Commission, Ursula Von Der Leyen, urged for a fundamental overhaul of the EU wholesale electricity market (WEM). As in her opinion the market no longer works as intended (Simon & Kurmayer, 2022). However, Schittekatte and Batlle (2023a) state price risk is mainly problematic in the long-term market, which implies the solution lays in redesigning this aspect, rather than the whole market.

Within this master's dissertation, the focus remains on how the design of contracts-for-difference serves as a hedging tool for long-term price risk. This should incentivize electricity developers to rapidly invest in renewable energy generation, not only to evade the Russian gas dependency but also to achieve the sustainability objectives of the European Union and let consumers benefit from the low operational costs stemming from this "green" energy (European Commission, 2023b). Further, this thesis provides an academical supplement to the existing literature on the suggestions for an optimal CfD design made by various authors in the last couple of years.

Initially, a literature review is made covering Chapter 2 and 3. First, to be able to efficiently assess an optimal CfD design, the structure of the current design of the EU WEM should be analyzed. Herewith, Chapter 2 describes the distortion of the price signaling function by addressing the shortcomings of this design. Secondly, Chapter 3 consists of a deep dive on the design of the CfD, departing from the inefficiencies the first CfD auction brought forth. As we proceed, this CfD will then be gradually tweaked, to dissolve different types of price distortion. Eventually, this leads to the most optimal design to be found in existing literature.

Lastly, Chapter 4 brings a comparative analysis of 2 existing CfD designs, implemented by respectively the Danish and Spanish regulator.

2 PRICE RISK IN THE EUROPEAN WHOLESALE ELECTRICITY MARKET

In the next chapters, the price signaling function is explained as well as key drivers to the distortion hereof. Hereby, the focal point concerns the main causes of long-term price risk influencing the investment decision within the EU WEM, as this aligns with the objective of this master's dissertation. It is crucial to acknowledge that this is not an isolated risk, and price distortion is influenced by various other factors.

2.1 The right price signals the right decisions

Hogan (2013) states that in principle, the European WEM should provide electricity prices incentivizing both flexible short-term operations for generators and positive long-term investment decisions for investors. In the short run, generators provide electricity in changing dispatch conditions (Hogan, 2013). When benefitting from the right price, operational and opportunity costs resulting from e.g., ramping-induced output, can be covered (Guo et al., 2021). Following the merit-order principle, active in Europe, this implies a price higher than the marginal operating cost of the highest marginal operating cost plant in the system (Trebbien et al., 2023). In the long run, the predicted revenues from investment are based on the expected short-term payments through a price high enough to cover these future investments (Hogan, 2013). In other words, the net present value (NPV) of these payments needs to cover operating costs and future amortization (CEER, 2021).

When looking at the demand side, Meeus et al. (2022) state that the correct electricity price reflects the generation mix behind the consumption of the end-user. The price signal for positive long-term investment decisions of investors, should then be efficiently transferred through a lower price for the consumer in the present (CEER, 2021). According to Schittekatte & Batlle (2023a), this transfer is guaranteed, if consumers are fully informed, possess full economic rationality and experience no entry barriers in a perfectly competitive long-term market. Further, they state that if these conditions can be met, consumers could naturally hedge themselves against persistent high prices in the future.

2.2 Price risk inherent to the current market architecture

Price volatility itself is not necessarily problematic as it is an inherent consequence of the scarce nature of electricity. Moreover, its non-storability and lacking demand response compels generators to adjust their output to short-term fluctuations (CEER, 2021). Next to these intrinsic factors, several external drivers affect price signaling within the EU WEM as well, such as natural gas price volatility, ETS prices, geopolitical tension, unusual weather conditions, competitiveness of the market … etc. (Kuik et al., 2022; Newbery, 2016). These factors can contribute to an unexpected push in volatility, creating uncertainty for generators, resulting in a higher risk premium enclosed in their long-term contracts (Soares, 2004; VaasaETT, 2022). Besides the risk drivers as mentioned ut supra, the distortion of prices can also be attributed to internal factors of Europe’s WEM design (ACER, 2022). Although this design changed throughout the last two decades, the current measurements, derived from prior EU energy packages, still insufficiently shield customers from sudden price shocks (Schittekatte & Batlle, 2023a; CEER, 2021).

The president of the EU Commission, Ursula Von Der Leyen, urged in her statement on June 8, 2022, for a fundamental overhaul of the WEM, as in her opinion the market no longer works as intended (Simon & Kurmayer, 2022). However, Schittekatte & Batlle (2023a) find that the spot market still functions as it is designed to do so—successfully coordinating the day-ahead market (DAM) and the intraday or real-time market (RTM). They also state that, contradictory to these short-term markets, the long-term markets never functioned properly compared to the beliefs of policymakers. Long-term contracts are not (and were never) liquid enough to hedge against the spot price risk for a time-horizon longer than two to three years (Schittekatte & Batlle, 2023a; ACER, 2023). Herewith, it is noted that illiquid contracts refer to investors not being able to find any counterparties, or find just those who are exceedingly expensive, to hedge their risk of generation investment (De Maere D’Aertrycke et al., 2017).

When regulators try to mitigate price shocks through a short-term intervention (e.g., EU Toolbox on electricity prices, (European Commission, 2021)), volatility in the long run can be inflicted (ACER, 2022). This can be endorsed by the following general guideline from the Agency for the Cooperation of Energy Regulators (ACER): “When an approach is more interventionist, the distortion of pricing is more likely to occur" (ACER, 2022). Hence, price shocks should spontaneously be captured by the design itself, to alleviate the burden on regulatory bodies, thereby eliminating their urge to intervene. Furthermore, if the intervention is not successful, Pollitt et al. (2022) state that a micro-economic shock can shift into a macro-economic shock, resulting in persistent high prices.

Consequentially, following Batlle et al. (2022), the problem cannot be solved by "shooting the messenger". They explain that the market design correctly signals a higher spot price when electricity becomes scarcer. Hereby, a complete suspension of the WEM design would not be justified, as it would affect the accumulated benefits from cross-border trade (e.g. enabling Member States to benefit from their neigh- bours' flexibility and adequacy solutions (ACER, 2022)). Alternatively, energy autarchy, where each member state provides its electricity for itself, would not be cost-efficient either (Batlle et al., 2022). Therefore, complementary adjustments to the design permits a more accurate long-term price signaling, without losing the accumulated synergies.

2.2.1 Missing money

As mentioned above, price volatility is inherent to electricity's scarce nature. When there is an incline in demand, a spike in prices can occur due to low electricity availability at a given moment in time. Farrell et al. (2018) state that in conventional WEMs this micro-economic shock should trigger investors to invest in additional capacity. Hereby, consequential to optimal operating decisions, optimal investment decisions can be made.

Alonso-Betanzos et al. (2017), state because of the inability of efficiently storing electricity, generators are bound by consumption prognoses to plan out their future output. Hereby, generators may have incentives to artificially raise prices during times of high demand by fabricating a false sense of scarcity (Farrell et al., 2018). Price caps are used to stop this kind of conduct but following Batlle et al. (2021), these are not an effective measurement. They come with the detriment of scarcity pricing and exacerbate the distortion of capacity investment incentives because they are capped far below actual demand levels (Newbery, 2016; Batlle et al., 2021).

These factors lead to the problem of “missing money” for future capacity expansion. This concept is also frequently associated with the capacity-expansion problem (Foley et al., 2010). The need for future capacity of electricity systems, which comes with strategic planning of the optimal generation mix (Foley et al., 2010). This planning of a secure, future electricity supply cannot be done precisely without a properly functioning long-term market. When the market signals the right price, it provides more certainty when it comes down to forecasting demand and supply used for investment decisions (Fuss & Vermeulen, 2008).

2.2.2 Missing markets

Since the start of the liberalization of the EU WEM, multiple hedging instruments have been developed to eliminate the exposure of market participants to long-term price risk (CEER, 2021). Hereby, long-term price risk essentially refers to the future price risk resulting from DAMs and RTMs (Algarvio et al., 2020). However, as mentioned priorly, derivate markets are unable to hedge price risk for larger volumes at a low transactional cost over periods longer than two to three years. This implies that a market for such contracts is “missing” or that derivative markets are “incomplete”. Key drivers hereof are clarified in the next paragraphs.

Schittekatte & Batlle (2023a) find that an underlying reason to why market participants limit their contract duration, can stem from vertically integrated utilities. These utilities hold a diversified generation portfolio and a broad consumer base. The authors explain further that this is how these market players are benefiting from a natural hedge from their own retail branch. Thus, they are not willing to provide long-term hedging to competing independent retailers. Besides, ACER (2023) mentions in its report on “Further development of the EU electricity forward market”, that hedging creates an entry barrier for independent market players, reducing the competitiveness of the market. Another factor explaining why hedging can be seen as a disadvantage to market players, can be found within the investor’s behavior. When an investor takes on higher risk levels, a higher financial return is expected (Ostrovnaya et al., 2020). Therefore, electricity developers can prefer to opt in for “going merchant”, signifying directly selling one’s output into the market absent from any hedging strategy (Schittekatte & Batlle, 2023a; Ostrovnaya et al., 2020).

Another reason for the illiquidity of long-term hedging can be found in the credit risk of market participants. The European Market Infrastructure Regulation (EMIR) imposes high-quality collateral requirements, rated by central clearing counterparties (CCPs), to enter trading on exchange markets (ACER, 2023). ACER (2022) states when prices, and herewith volatility, rise, the collateral requirements grow as well, resulting in a higher bank guarantee to hedge future price risk. Herewith, Newbery (2016) states it is difficult for developers to convince banks and shareholders of the credence of their investment plans as these are based on projected revenues. Hence, this prompts market participants to be cautious, creating a disincentive for hedging at power exchange markets.

The importance of the concepts of missing money and missing markets has only increased as the EUs renewable electricity targets become increasingly ambitious (Newbery, 2016).

2.3 The road to net-zero

Besides the inherent price risk of the WEM structure, EU regulation obligates market agents to adapt to its new objectives. As a result, generators carry a collective obligation to invest in specific investments, driving up their capital expenditures (CapEx) (Egenhofer et al., 2022). Considering the objectives of the “Fit for 55” package, an additional investment in renewable energy sources (RES) is needed by 2030 to achieve net zero emissions in 2050 (Gas for Climate, 2021). This implies a doubling in the total installed RES capacity from 2021 to 2030 (European Commission, 2022; Statista, 2023). With a high debt-to-equity ratio (D/E ratio) and uncertain future revenues, generators are in a vulnerable position to price volatility (Newbery, 2023).

2.3.1 Intermittency of RES

Besides higher CapEx, the EU WEM is impacted by the intermittent output of renewable energy systems. Following a report of the EEA (2023), these systems accounted for 37,6% of the market’s total installed capacity in 2021. The EU’s commitment to achieving 45% RES in its overall electricity output by 2030, necessitates the gradual accumulation of these intermittent systems over time (EEA & ACER, 2023). The intermittency of renewable resources, especially for solar energy, results in a mismatch between end users' consumption and the availability of RES (Schittekatte & Batlle, 2023b).

In a study from the International Monetary Fund (IMF), Cevik and Ninomiya (2022) state that following the merit-order effect, when renewable supply is lacking, other, more conventional energy resources in the energy pool must cover this shortage to meet demand. This effect potentially leads to a higher hourly market clearing price, thus the price offered by a more expensive generator (Zachmann & Heussaf, 2023). Hereby, the "inframarginal" generators, those who generate at a lower operational cost, receive a much higher price than this cost (Grubb et al., 2022). Conversely, when there is excess generation introduced to the pool market by renewable energy systems, this can potentially lead to a decline in prices (Cevik and Ninomiya, 2022). Nevertheless, Cevik and Ninomiya (2022) found some evidence that RES have a dampening effect on price volatility at the highest quantiles based on their quantile regression approach.

Lastly, Fabra (2022b) states the design of long-term contracts must differ across technologies depending on their flexibility in responding to short-term price signals. Herewith, intermittent RES technologies are more vulnerable to short-term prices and require more hedging than less intermittent technologies such as hydropower (Fabra, 2022b).

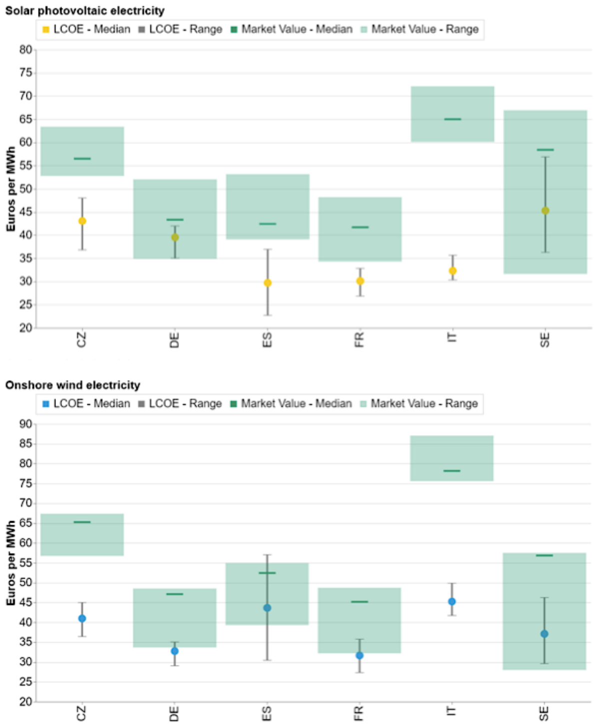
2.3.2 Cost-competitiveness of RES

Another principal rationale seems to be present to why variable RES support systems should be integrated into the current EU WEM design, rather support systems for alternative technologies. Newbery (2023) states that the reason hereto lays within the learning benefit of variable RES technologies. He explains that the accumulation of R&D, design and production economies of scale enables a more efficient deployment, which drives down future costs. A crucial aspect is that the educational spillover arising from these renewable technologies is contingent on their installed capacity rather than the subsequent output they generate. (Newbery et al., 2018).

However, a learning spillover may not determine the cost-competitiveness of RES technologies compared to alternative electricity technologies. An effective methodology to measure the competitiveness of RES technologies, can consist of determining the Levelized Cost of Electricity (LCOE) and analyzing market value trends of electricity resources (Shen et al., 2020; Hirth, 2013). The LCOE signifies the mean revenue per unit of electricity produced necessary for recuperating investment and operational expenses over the project's technical lifespan (Busch et al., 2023). It combines the burden of high upfront capital costs with the advantage of low short-run running costs. When the LCOE is plotted against its future market value, the LCOE should preferably lay below the RES its future market value to achieve cost-competitiveness. Busch et al. (2023) analyzed this comparison for onshore wind and solar photovoltaic electricity in representative market conditions by 2030. In the subsequent graph, attaining this cost-competitiveness can be observed for a sample of six EU Member States.

Figure 1

Cost-competitiveness of on-shore and solar photovoltaic electricity by 2030



Note. Adapted from: Busch, S., Kasdorp, R., Koolen, D., Mercier, A., & Spooner, M. (2023). The development of renewable energy in the electricity market (No. 187). In the public domain.

Current RES support schemes, opposing price volatility, are based on preconceived subsidies or strike prices, which determine the revenue for RES (Newbery et al., 2018). These schemes only pay out a pre-arranged amount when actual RES generation occurs. Hereby, the current framework causes locational and dispatch distortions (Newbery et al., 2018). Newbery (2023) explains to enable the energy transition through efficient long-term markets, it is necessary for the EU WEM to provide new renewable support systems.

3 ESTABLISHING CFDS TO HEDGE PRICE RISK ON THE EU'S WHOLESALE ELECTRICITY MARKET

Over the past decade, numerous authors have advocated for a redesign of Europe's WEM. Despite these calls, regulators did not undertake profound action until a the eruption of the war between Russia and Ukraine induced a price shock because of the EU's gas dependency of Russia (European Commission, 2023b). This prompted an immediate need to revise the regulatory framework of the EU WEM (European Commission, 2023a). Schittekatte and Batlle state the reason hereto as follow: "(Marginal) energy prices have reached sustained and never expected high levels, and there are reasons to think that this is not necessarily going to be an exceptional situation" (Schittekatte & Batlle, 2023a, p.2).

3.1 Proposal on the 5th EU electricity market reform

On the 14th of March 2023 the EU Commission published its proposal on tackling the deficiencies of the EU WEM design, which was preceded by a public consultation on the 23rd of January 2023 (European Commission, 2023c). The proposal consists of revising several legal acts to oppose price volatility, further accelerate investments in RES, and enhance grid flexibility (Widuto, 2023). Herewith, it is considered a proposal for the 5th EU electricity market reform, however, without recommending a fundamental overhaul (Widuto, 2023).

Although the EU Commission quotes multiple amendments of the EU WEM design, this study remains focused on the Commission's main thrust: complementing short-term markets by stable price signals stemming from longer-term contracts, while incentivizing the deployment of clean-energy technologies (Zachmann & Heussaf, 2023). Following the Commission, governments should be encouraged in partly bearing the long-term price risk of Power Purchase Agreements (PPAs) through public tendering and in recommending two-sided Contracts for Difference (CfDs) as the default instrument to non-fossil generation contracts (European Commission, 2023c). Schlecht et al. (2023), note herewith that the implementation of CfDs is rather seen as a supporting scheme to the EU WEM, rather than a redesign of its current structure.

3.2 Recent developments after the Commission’s proposal

It is within the role of the European Council to have technical discussions and to legislate based on the Commission’s proposals (European Council, 2023a). The Council's preliminary stance, known as the general approach, streamlines the EU legislative process by facilitating mutual agreement with the European Parliament (European Council, 2023a). On October 17, 2023, the Council's Working Party on Energy announced the general approach to take on clearly defined strategies in propagating the Commission’s proposal on the EU WEM’s “redesign” (European Council, 2023a). On the 14th of December 2023, a preliminary decision between the two legislators (the Council and the Parliament) was reached. This decision entails a final draft, preceding their ultimate decision within the legislation process (European Council, 2023a).

3.2.1 Provisional Agreement

Concentrating on the aim of this thesis, the preliminary decision (also known as “the provisional agreement”) resulted into agreeing on the following key takeaways in generalizing two-way CfDs for long-term electricity markets (European Council, 2023b):

- Two-way CfDs would be utilized for investments in emerging power-generation facilities, encompassing wind, solar, geothermal, reservoir-less hydropower, and nuclear energy.
- When public funding would be involved, doubled sided CfDs should be the mandatory model to employ. However, this obligation loses relevance when member states alter conditions, negatively affecting rights and economic viability of current RES projects with state funding[1].
- To uphold a stable and predictable legal framework for ongoing projects, legislation only comes into effect after a transition period of three years.
- The provisional agreement allows flexibility in redistributing revenues generated by the state through two-way CfDs. This results particularly in allocating these excess revenues to final customers directly or by financing direct price support schemes or cost-reducing investments.

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[1] Renewable Energy Directive. Directive (EU) 2018/2001, art. 6.

Ultimately, the Council and the European Parliament agree on the provisional agreement they constructed together, which is referred to as the “codecision” (European Council, 2023a). It is the formal adoption process that would be anticipated in the early months of 2024 (European Commission, n.d.-a).

To counter this proposal, Morawiecka and Scott (2023a) describe imposing two-way CfDs as the mandatory instrument for emerging RES-E technologies is the most interventionist approach that could have been decided. Hereby, they explain this approach brings about risks lowering the pace and volume of RES deployment by ruling out merchant RES participation. This stands in stark contrast with the investor’s tendency on going merchant (see 2.2.2). In this light, the considered approach within the proposal might be too strict. This can result in investors pursuing a way around the contract, and herewith missing its aim. This was the case for the Danish hybrid wind CfDs (see 4.1). Optimally, a CfD design would consider the investor’s preference for “going merchant” and would aim to find a balance between the level of interventionism and the allowance of merchant risk. In the search for such design, further research could be explored through e.g. the work of N. Gohdes, P. Simshauser and C. Wilson on optimizing the CfD-merchant revenue mix (Ghodes et al., 2023).

The following chapters will focus on examining these double-sided CfDs as a solution to mitigate long-term price risk and incentivize future investment in RES. Hereby, contributing to the EU's net-zero objectives while preserving the short-term market price signaling function. However, first, the Feed-in-Tariff (FiT) structure is briefly analyzed as it was the CfDs predecessor (see 3.3). This support mechanism enabled the scale-up of RES deployment throughout Europe (Manjola et al., 2017).

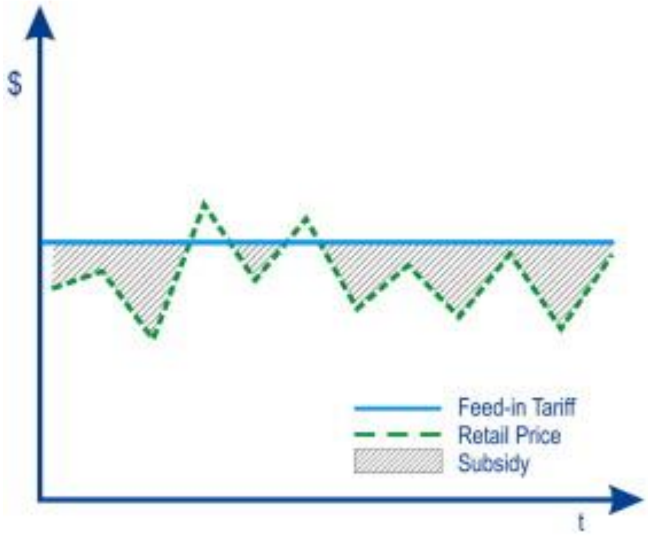
3.3 Feed-in-Tariffs facilitating RES deployment in the last decennia

Over the course of the EU’s energy policy history, Feed-in-Tariffs (FiTs) stood out as a pivotal tool in the pursuit of the development of RES technologies across Europe (Manjola et al., 2017). Emerging in the late 20th century, FiTs were designed with the specific aim to incentivize the adoption and development of nascent renewable energy technologies, while fostering energy independence and mitigating the effects of global warming (Pyrgou et al., 2016). The EU commission envisioned the FiT instrument as the most effective policy to encourage the rapid and sustained deployment of RES (Couture & Gagnon, 2010).

3.3.1 Technical structure

Newbery et al. (2018), explain FiTs resort under the heading of RES subsidies, which implies a fixed amount is received by generators for a fixed duration. The mechanism behind FiTs consists of guaranteeing a fixed price based on the specific development cost of the technology for every kilowatt-hour (kWh) of electricity sold to the grid (Couture & Gagnon, 2010). The price point on which the fixed payouts are based, is set administratively above the market price (Pyrgou et al., 2016). Further, utility companies were obliged to buy any RES generated electricity (Rowlands, 2005). The structure of a FiT can be visualized as is apparent from the below graph.

Figure 2
Feed-in-Tariff principle



Note. Adapted from: Couture, T. D., & Gagnon, Y. (2010). An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. Energy Policy, 38(2), 955–965. In the public domain

3.3.2 The rise and fall of FiTs in Europe

Throughout the late 1990s and into the 21st century, FiTs gained widespread popularity in Europe. The first member states implementing this arrangement were Germany and Denmark and Spain for the deployment of wind energy (Cointe & Nadaï, 2018). With

Germany doubling its wind energy capacity year-on-year during 1990 until 1995, these projects spurred a market-wide acceleration in adopting and developing RES technologies in Europe (Klein, 2012; Pietruszko, 2007).

However, the limitations and unintended consequences of the FiT scheme soon became evident. Fouquet and Johansson (2008) explain how costs stemming from FiT payments are in general passed on to the electricity consumers, resulting in higher retail prices. Additionally, the success of FiTs in stimulating renewable energy deployment resulted in a surge of installations, putting a strain on the flexibility of the grid operator, causing grid congestion (Schermeyer et al., 2018).

Furthermore, as technology advanced and the costs of renewable energy technologies declined, the need for such generous incentives diminished. As price setting was done administratively, governments could not keep pace in lowering the price level to the rate of decline in investment costs (Morawiecka & Scott, 2023a). Due to the FiTs’ efficacy in accelerating RES deployment, it shows that the pricing was established at an excessively elevated level (Zhang et al., 2014). This can result in welfare losses for society and over rewarding inefficient RES developers and operators, (Lesser & Su, 2008). Moreover, Newbery et al. (2018) explain their generosity often distorted location decisions and raised system costs. Consequentially, the lack of competitive pricing creates a disincentive for further innovation by RES developers (Sijm, 2002).

By the end of the 2010s, the era of FiTs in Europe had reached its conclusion. The EU Commission urged in its statements for a gradual reduction in subsidies between 2020 and 2030, as well-established renewable energy sources will attain grid competitiveness (Boasson et al., 2020). The FiT scheme had played a crucial role in jumpstarting the renewable energy revolution (Groba et al., 2011). Nevertheless, its termination reflected a maturation of the industry and a recognition that more economically efficient mechanisms were needed to sustain ongoing RES deployment (Rövekamp et al., 2021).

3.4 CfD peculiarities

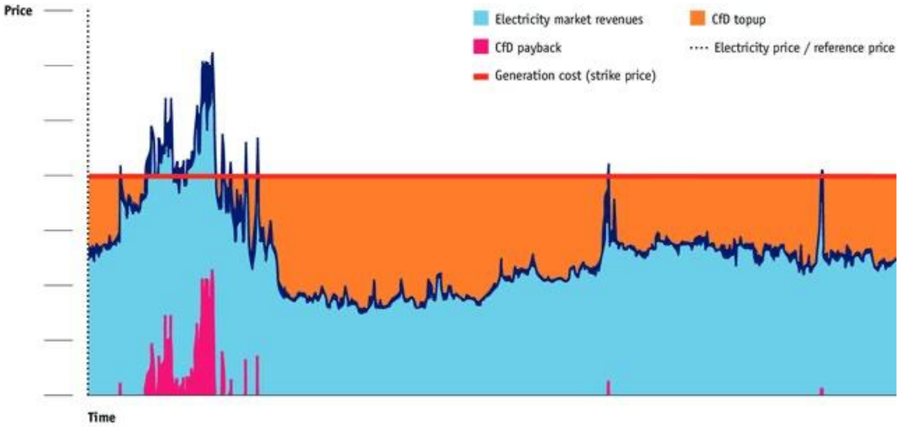
CfDs as derivative products on the financial market began to be traded around the 1990s in the United Kingdom (Corbet, 2012). This instrument was applied so traders could leverage the capital gain of owning stocks without the necessity of actual ownership (Corbet, 2012). Presently, the derivative product is recognized as a pivotal support mechanism in facilitating a sustainable and environmentally conscious transition for Europe (see 2.1). The following paragraphs will examine this instrument as a financial derivative and how it can be implemented within the electricity sector.

3.4.1 A financial derivative product

The fundamental concept underlying a CfD may be described as a financial derivative arranged through a bilateral agreement, entered between a CfD provider and an investor (Schlecht et al., 2023). The trading parties agree on a strike price for an agreed upon duration (usually 15 to 20 years) (Lopes & Coelho, 2018; Morawiecka and Scott, 2023a). When this designated period ends, the difference between the pre-established "strike price" and the prevailing market value of the underlying is disbursed (Schlecht et al., 2023). Batlle, Schittekatte, and Knittel (2022) explain this difference is often referred to as “the spread”. When there is a decline in price towards the strike price, the loss is paid out by the investor to the CfD provider and vice versa (Alonso-Betanzos et al., 2017). As such, Lopes and Coelho (2018) suggest that a CfD can be seen as a combination of a call and a put option integrated into a single instrument. Further, Kitzing (2023) explains that renewable CfDs are called fixed-for-floating swaps. She explains herewith that the fixed and floating rates are examined and financially reconciled with each other to determine the net payment obligation between the involved parties for every settlement period. The below graph illustrates the upward and downward movement of the underlying asset’s price/ the reference price around the strike price, visualizing hereby the price spread.

Figure 3

Graphical representation of CfDs



Note. Adapted from: Sawyer, S., Shukla, S., Jones, F., & Menezes, R. (2014). Offshore Wind Policy and Market Assessment - A Global Outlook. In *ResearchGate*. FOWIND 2014. In the public domain.

3.4.2 Hedging principle

Besides the previously explained concept “missing markets” (see 2.2.2), Kitzing (2023) explains further how CfDs are used to hedge against future, long-term price risk on the derivative market. She states that this type of product enables hedging against the future uncertain value of the different underlying assets. Safuan et al. (2022) state that the underlying can take the form of, inter alia, currencies, commodities, stocks, and indices offered through over-the-counter (OTC) arrangements. Changes in the value of this underlying are a trigger for payments between contracting parties, devoid of the underlying ever-changing ownership (Kitzing, 2023).

For electricity markets this means, when concluding CfDs, there is no physical delivery of electricity between the contracting parties (Oliveira et al., 2013). Hereby, Simshauser (2019) states that the underlying embedded in these contracts refers to a predetermined spot price (see section 3.5). Consequentially, CfD implementation can be seen as a move from commodity-based to asset-based economics (Grubb et al., 2022).

An argument to how electricity CfDs distinguish themselves from the CfDs traded on derivative markets, can be found in the magnitude of the underlying quantity being hedged. Schlecht et al. (2023) state this alludes to the weighting of the price spread. They explain that by multiplying the established price spread with the electricity output sold, starkly contrasts with the “traded financial derivative CfD”. This is because the traded CfDs are traded on margin, representing solely a fractional proportion of the predetermined quantity (Peshev, 2021). Peshev (2021) mentions that this is how the investor can leverage its initial investment without paying for the full volume of the underlying.

While both traded CfDs and electricity CfDs make a distinction between payments and output, they are still conducted differently. Electricity CfDs are concluded based on a predetermined volume (Fabra, 2023). This guarantees the quantity required from a generator to provide off-takers with operation coverage or retailers with client provisioning. By multiplying the electricity output with the price spread, the price spreads are weighted (Schlecht et al., 2023). For traded CfDs, only a portion of this volume is contracted, allowing the trader to leverage his investment. Consequentially ownership of the output, is not relevant for his case.

Henceforth, when referencing the term CfDs in this dissertation, it is excplicitly referring to electricity CfDs.

3.5 Conventional CfDs on the EU WEM

Applying CfDs as a hedging instrument on long-term markets, is not an unprecedented practice in Europe. In 2013, the UK introduced its Electricity Market Reform (EMR), being a pioneer in implementing CfDs by government policy into the country’s electricity sector (Grubb et al., 2022). Herewith, the Low Carbon Contracts Company (LCCC) introduced its first CfD allocation round from October 1st, 2014, until March 2015 (Department for Energy Security and Net Zero, 2023). Given the evolution of electricity CfD pricing since 2014, understanding its foundational origins becomes crucial. In this section a brief explanation of the transactional structure is given, to then clarify the determination of the strike price, reference price/ the electricity price itself for these conventional CfDs. Lastly, its shortcomings are summarized, explaining how its functionality is now rather outdated.

3.5.1 Decoupling output sold on the DAM from payments

Schlecht et al. (2023) explain how a CfD contract consists of two separate financial transactions. First, both trading parties sell and buy a predetermined energy quantity through a spot market/ the energy pool (Oliveira et al., 2013). Both parties hereby engage in trading on the DAM, like any other market participant, should there be no additional agreement in place (Lopes & Coelho, 2018). Fabra (2023) explains that afterwards generators pay or receive the difference between the strike price and reference price to or from their counterparty. This type of CfD is called a two-way CfD. Further, she mentions for instances where only a singular party takes up the financial obligation, the contractual agreement is referred to as a one-way CfD.

Finally, the mechanism behind CfDs enables a decoupling of the reimbursement between parties from the actual output delivery (Zachmann et al., 2023). Lopes and Coelho (2018) further state that customized CfDs enable market participants to engage in the centralized day-ahead market while shielding them from market-clearing prices. Essentially, they state, CfDs serve as a long-term hedge against price volatility without interfering on the DAM. Lastly, in an optimal situation this benefit of hedged risk should result in transferring back revenue to consumers, to compensate them in times of high prices (Middelburg, 2023).

3.5.2 Conventional CfD pricing

Section 3.3.2 addresses the underlying asset of a CfD, specifically noting its association with a predetermined spot price. However, Schlecht et al. (2023) emphasize that this condition pertains solely to the conventional CfDs, referring hereby to their original form introduced in the UK in 2014. Within this context, conventional CfDs are perceived as the most traditional form of CfDs. Its payment structure can be outlined as follow (Lopes & Coelho, 2018):

$$\text{Payment}_t = (\text{strike price} - \text{spot price}_t) \text{ x produced volume}_t$$

When applying this formula, a positive outcome implies a payment is made to the generator from the electricity off-taker for a designated timeframe $_t$. Conversely, a negative payment would resemble a reimbursement from the generator to the electricity off-taker. As already mentioned in section 2.4.2, the price spreads of conventional CfDs are weighted by the electricity output, which can also be derived from the above formula.

3.5.3 Strike price

As already explained in section 3.4.1, the strike price is a pre-determined fixed price at which the off-taker of the contract agrees to purchase, or the generator agrees to sell, the electricity output. The fixed price setting is used to provide a guaranteed revenue stream for the renewable energy source electricity (RES-E) producer (Wild, 2017). This determination can be done through a(n) (bilateral) administrative process or by competitive auctioning (Beiter et al., 2023).

Administrative price setting

When concluding a conventional CfD, in the absence of a competitive price setting process, the strike price is determined administratively by the regulator or by negotiation between the two contracting parties (DECC, 2012). The UK's Department of Energy & Climate Change (DECC) (2012) explains that this occurs when market conditions are not yet favorable for the implementation of a competitive price setting process. The country was the first to implement CfDs as a hedging tool in developing their offshore wind farms (see 3.5). Hereby, the UK government was not ready to implement a competitive price setting scheme yet, which resulted in being the only jurisdiction where a regulator set the strike price administratively (Beiter et al., 2023).

The UK regulator adopted the framework of their Renewable Obligation (RO) banding review process to provide strike price guidelines for CfDs issued by the LCCC in its first allocation round in 2014 (DECC, 2012). The RO banding review served as the previous RES-E support mechanism, which as of 2012, the UK planned to transition away from (Oxera, 2015). The price setting guidelines embedded within this policy can be summarized as RO minus X or RO-X (DECC, 2013). Essentially, this implies that the minimum expected rate of return of a RES-E project, expressed as the hurdle rate, should lay below the hurdle rate of the projects which were granted the RO support (DECC, 2013; De Maere D'Aertrycke et al., 2017).

The single example to be found on conventional CfDs solely concluded under bilateral negotiation is the Final Investment Decision Enabling for Renewables (FIDeR) process (BEIS, 2019). These FIDeR contracts are again constituted by the UK regulator the run-up to the UK's Energy Act (DECC, 2014). They consisted out of CfDs for nuclear generation and CfDs for 8 specific renewable energy projects (BEIS, 2019). The RES-E projects are relating to the conversion of two coal-fired power plants to biomass power plants, 5 offshore wind farms and one bio-mass combined heat and power plant (DECC, 2014). With nuclear energy and 8 renewable energy developers, the strike price had to be negotiated bilaterally with the UK government. However, as the consumer was burdened with the costs running up to £16.6 billion, administrative pricing was not considered as a viable price setting scheme (DECC, 2014).

The Association for Renewable Energy & Clean Technologies (REA) argued that with this method there is an absence of credible real-world cost data on projects which is essential for establishing strike prices (REA, 2022). Kitzing (2023) explains if strike prices are set too high and references prices remain rather low, this could potentially lead to a constant pay out to the developer. This effect would convert two-sided CfDs to one-sided CfDs. In 2014, the EU decreed that, in principle, price setting support should be granted through competitive auctions (Morawiecka and Scott, 2023a). The EU emphasized that, contradictory to administrative processes, CfDs can hereby obtain optimal cost discovery (Morawiecka and Scott, 2023a).

Competitive price setting

As mentioned in section 2.3.2, competitiveness of a RES technology can be measured through the LCoE. However, Jansen et al. (2020) explain how LCoE data is not always widespread available. Nevertheless, they state that (particularly for offshore wind), the investors' expected LCOE can be derived from auction results, as data on successful bids is openly published. Additionally, ACER (2022) states in its report on EU WEM design that tenders or auctions serve as a tool to identify adequate levels of financial support, by ensuring that prices are set competitively. Thus, auctions serve as a price-discovery mechanism (Welisch, 2016).

In 2005, Denmark was the first country implementing an auction to allocate the length of state support on RES-E development projects, with its tender for two-way, offshore wind farm subsidies (Jansen et al., 2020). However, the first auction allocating state support specifically through CfDs, was concluded in the UK in 2015 (Jansen et al., 2020). Herewith, the National Grid (NG), the UK's transmission system operator (TSO), organized its first auction (Newbery, 2023).

Beiter et al. (2023) explain how the regulator can embed the option for an auction design limited to a single asset type (for example, only offshore wind) or multiple generation asset types, also referred to as technology-neutral auctions (Schlecht et al.2023). The NG made a budget distinction between established (e.g. solar and onshore wind) and-less established (e.g. anaerobic digestion, offshore wind) technologies (Welisch & Poudineh, 2019). Hereby, it can be considered that the auction bidders were developers from multiple generation asset types. With this type of auctioning, it is important that the different awarded contracts are for each type of asset designed according to their specific characteristics (Fabra, 2022b). Lastly, some examples of single asset auctions are the German and Danish offshore wind power auctions (Morawiecka & Scott, 2023a).

Welisch and Poudineh (2019) explain that first the auction participants should pass the pre-qualification criteria (e.g. valid permitting). After their qualification, they include specifications with the bids they submit such as information about the technology type, their strike price, the capacity, and the delivery year of the project. The bidders' applications are then ranked based of the strike price they submitted (Welisch, 2016). Wild (2017) explains bids are selected starting with the lowest and progressing through to higher bids, until the target capacity for renewable energy in that auction round is met. Hereby, this type of auction design is often called a reverse auction, which is used in the contract design of the UK's first CfD allocation round (Wild, 2017). If the amounts linked to these applications surpass the regulator's budget, there is an auction held to allocate the contracts through a pay-as-cleared format (Welisch & Poudineh, 2019). This implies the bidders with strike prices on or below the clearing price, are awarded the contracts with a uniform strike price being the clearing price (Welisch, 2016). If applications do not result in a budget or capacity breach, contracts will be granted without competitive bidding, using a price set administratively (Welisch & Poudineh, 2019).

Alonso-Betanzos et al. (2017) explain how the second phase of the procurement process involves a private one-on-one negotiation between the auctioneer and each of the chosen investors to arrive at a mutually agreeable strike price. Each selected investor is aware of the initial strike price proposals other investors put forth within the first phase, as CfD auctions consist of sealed bids (Welisch & Poudineh, 2019). Hereby, sealed-bid auctions involve simultaneous bid collection and ranking, whereas open-bid auctions allow investors to adjust bids after observing others' offers (Welisch & Poudineh, 2019). Consequentially, during the negotiation phase of this sealed bid-auction scheme, an opportunity arises for developers to submit a more competitive offer (Alonso-Betanzos et al., 2017). Once the strike price is finalized and contracts are awarded, the strike price receives an annual inflation adjustment (GOV.UK, 2014). This is implemented through the Consumer Price Index (CPI) to preserve purchasing power (Morawiecka & Scott, 2023a). Hereby the strike price set in 2012, becomes the Adjusted Strike Price for each contract year (Bowden, 2023).

The EU commission states this pricing model provides efficiency, transparency, and incentives to drive down the generator its CoC (European Commission, n.d.-a). They state there is a general consensus on a pay-as-cleared principle being the best solution within liberalized markets. This because it is a highest accepted bid auction which starts with accepting the lowest bids first (European Commission, n.d.-a). The alternative would be a pay as bid auction, where the generator predict the market clearing price, and above their marginal costs (Willems & Yu, 2022). Winners are afterwards awarded with the bids they initially submitted (Willems & Yu, 2022). Their bid is independent from their true generation costs, and does not provide incentives to bid at zero euro per megawatt-hour (EUR/MWh) (European Commission, n.d.-a)

Lastly, regulators also embed an administrative strike price within their competitive price setting process (BEIS, 2022). This to put a maximum price per MWh the Government is willing to offer developers for each technology type, which is often referred to as the reserve price (BEIS, 2022). Hereby, Newbery (2016) explains how administrative strike prices were converted into ceiling prices to align with the budget cap of the auctioneer within a competitive price setting context. This because the hurdle rate (the Weighted Average Cost of Capital, WACC) determined to conduct administrative strike prices was, too high, which is why a competitive price setting is preferred (Newbery, 2016).

3.5.4 Design implications of competitive price setting

According to Fabra (2023), in an auctioned CfD pool (see 2.6) the strike price should reflect the average cost of the most expensive accepted unit. It also should reflect the average costs of the inframarginal plants if technologies and site characteristics are similar. She further points out that this last statement can only occur under the condition that competition is sufficiently present. However, when analyzing the auction design of different European countries, auction design can involve investor risk leading to uncertainty for the RES developer creating incentives for speculative bidding (Welisch & Poudineh, 2019).

Policy-induced uncertainty affects the cost of capital (CoC)

Welisch and Poudineh (2019) explain how the first allocation round of CfDs in the UK came with an uncertain cost projection of future technology development and with the uncertainty surrounding the construction of the planned capacity. Hereby, Kell et al. (2022) emphasize on the importance of a correct bidding strategy. Moreover, they explain how developers who submit overly high bids and do not secure contracts, are at risk of experiencing project delays as they await the next allocation round. Conversely, developers who win contracts but fail to accurately assess their own costs may submit bids that were too low.

Welisch (2016) explains how the auction's clearing price can either be determined by the highest accepted or the lowest rejected bid. Winning with the highest accepted bid creates an incentive for developers to exaggerate their CoC, manipulating herewith the clearing price. On the contrary, winning with the lowest rejected bid, high or low capital costs do not influence the clearing price. In conventional CfD auctions, the former awarding method is used which allows manipulation of the auction's outcome, and thus the strike price (Welisch, 2016).

Winner's curse

As the bidder inserts bids that concern different commissioning years in the future, it is difficult to forecast the project's future cost structure correctly (Welisch, 2018). Hereby, the regulator embedded penalties to prevent the developer from not delivering the RES-E project. The format in which these penalties come is determined by country specific policies (Jansen et al., 2020). For example, for general RES support auctions in Germany the penalty consisted of reduced support per kWh (by 0.003 €/kWh) (Kreiß et al., 2017). For conventional CfD auctioning, the applied penalty consisted of excluding the developer from bidding within the next two allocation rounds (Welisch, 2018). However, this penalty is not seen as stringent enough to receive more transparency from the developer on his ability in delivering the RES-E project (Welisch, 2018). This might imply that bids are seen as options for project construction by RES-E developers (Jansen et al., 2020). Additionally, as mentioned ut supra, the traditional CfD design allows strike price manipulation.

Following Welisch and Poudineh (2019), these aspects of auction design can result in a common risk in auction design called the "winner's curse". This term signifies developers strategically or unintentionally submitted bids that are too low, and as a result, they cannot cover their costs because the final strike price is insufficient. Lastly, they showed that implementing a stringent non-delivery penalty inducing truth telling can improve the deployment rate without increasing support costs. In conclusion, this shows that, contrary to administrative price setting, a strike price set too low can be inefficient as well.

Limiting uncertainty stemming from auction design

Different approaches can be found to curtail the uncertainty for developers participating in CfD auctions. Kell et al. (2022) suggest game-theoretic principles to define optimal bid strategies for generators attempting to win a CfD contract. Additionally, Welisch and Poudineh (2019) aim for regularly scheduling in allocation rounds, as the learning benefit of cost decreases in technology can be incorporated into the developer's bids in subsequent auctions. Moreover, Newbery (2023) emphasizes on the importance of clarity on future policies for developers, as this may impact their awarded contract its future value. Further, Jansen et al. (2020) explain the presence of cross-country variation in auction design aspects, which complicates the comparability. The solution to diminish the developer's uncertainty lays within a different approach for each country (Jansen et al., 2020). Lastly, Beiter et al. (2023) state the adequacy of centralized procurement can be doubted, given the trend of market liberalization over the last decades. However, they state that CfDs serve as a replacement of feed-in tariffs, rather than adding a new jurisdiction to the instrument pool.

This section shows that not only the volatile electricity market price causes uncertainty for the RES-E investor. Additionally, depending on the auction design, the uncertainty of winning the auction creates a deterrent to the deployment of RES as well.

3.5.5 Reference price

Simshauser (2019) explains how the underlying asset embedded within conventional CfDs refers to the hourly spot price of derived from the DAM (currency/MWh). Herewith, the hourly spot market clearing price can be seen as the reference price for conventional CfDs. Nevertheless, Kitzing (2023) states that in principle, the choice of reference price can be agreed upon freely and is not necessarily the current market price. She also mentions an evolving trend in reference price determination in Europe. Hereby, not the hourly day-ahead price is used as the reference price, but rather a longer-term average hereof. Such alternative reference prices are further elucidated in section 3.8.4 and Chapter 4.

Price distortion on the intraday market

Schlecht et al. (2023) state the hourly DAM spot price as the underlying is not seen as most efficient to implement in a CfD. They explain how this underlying causes distortion on the intraday or balancing market. The CfD payment is only occurring under the condition that the generator offers his output on the wholesale market. Hereby, when the strike price is set after the auction's closing, the underlying provokes an opportunity cost related to the CfD its payment obligation, which causes distortion. However, price distortion transpires differently during high-price and low-price hours on the DAM.

Schlecht et al. (2023) explain that when the balancing price on the RTM is significantly lower than the day-ahead price, the generator will choose to curtail its production. This to avoid an excessive payback, conducted under a high reference price (exceeding the strike price). Hereby, low-cost RES-E is wasted. This underproduction may cause inflated prices (Hirth, n.d.). On the contrary, when the real-time price is extensively surpassing the day-ahead price, the generator can experience an opportunity cost on the downside in the market (in other words, when the strike price lays above the reference price) (Schlecht et al., 2023). The opportunity cost reflects the pay out by the regulatory body, from which its value lays below the value of the generators output sold on the intraday market. Hereby, the generator is missing out on revenue and is incentivized to drive up its output, which can cause a depression in prices (Hirth, n.d.). Further, Newbery (2023) highlights the possibility of congestion constraints caused by overproduction.

In this view, the generator its decision-making regarding his output is purely based on the avoidable costs (excessive payback) and avoiding opportunity costs (potentially losing revenue) (Newbery, 2023). Schlecht et al. (2023) explain when the real-time price from the balancing market would be considered as the underlying of the CfD, this would cause generators to dump their output. Thus, this does not provide a solution to the distortion on the short-term intraday and balancing markets.

3.5.6 The issue of produce-and-forget

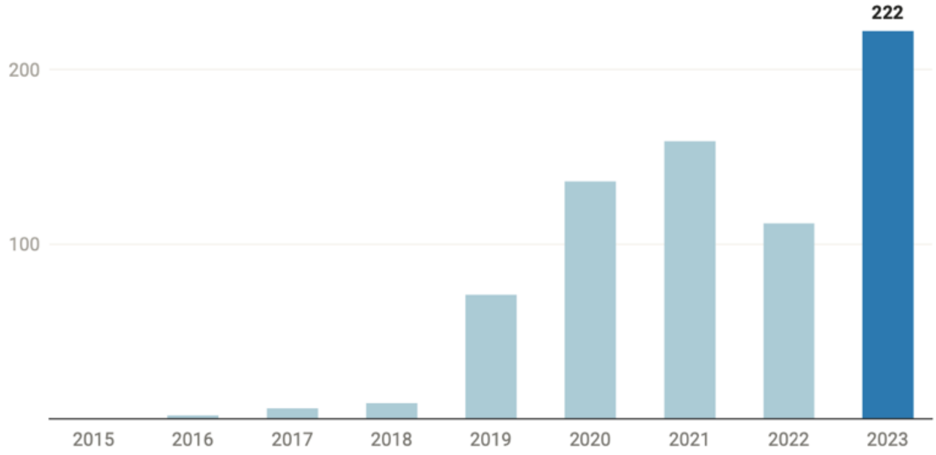
Morawiecka and Scott (2023b) explain that the issue of "produce-and-forget" arises when CfDs encourage project developers to focus on initial energy production, while neglecting long-term performance and maintenance. They explain that essentially, the generator captures the CfD strike price for each dispatched energy unit, irrespective of the wholesale price. Consequently, the generator does not perceive increased or declined prices as incentives to respectively raise or reduce output. This implies a distortion of the price signaling function, causing a dispatch distortion which can be exacerbated by obligatory priority dispatch for RES-E (Newbery, 2023). In a scenario where each produced MWh is awarded with a payout, the generator is motivated to always maximize his production (Newbery, 2023; European Commission, 2023d).

Negative prices

A recent news article from De Tijd showed an upward trend in yearly hours with negative prices on the European Power Exchange (EPEX) since 2019 (Steel, 2024). In 2023, a record number of 222 hours was counted (see Figure 3). This due an accruing availability of renewable energy, causing wholesale prices to further plummet. When the generator produces excess electricity, price cannibalization can occur due to oversupply of low-cost RES-E and reduced demand, which can cause the market equilibrium to lay below zero EUR/MWh (Moerenhout et al., 2023; T. Oliveira, 2023). This implies generators must pay to supply their output to the grid. Additionally, industrial consumers receive revenue by buying electricity directly from the EU WEM (Steel, 2024).

Figure 4

Quantity of hours with negative prices on the wholesale market (EPEX) from 2015 until 2023



Note. Adapted from: Steel, T. (2024, January 2). *Stroomprijzen duiken vaker dan ooit onder nul*. De Tijd. In the public domain.

Further, in an undistorted market, when negative wholesale prices lay below the variable cost of generators, generators would be incentivized to curtail their output (Hirth, n.d.). However, due to the dispatch distortion caused by CfDs, generators fail to recognize these incentives, as they continue to receive compensation for their produced output (Morawiecka & Scott, 2023b). Herewith, the generator its revenue loss incurred by selling its output on the WEM is compensated by the payouts still received from the government (WindEurope, 2022). This leaves no incentive to curtail his output (WindEurope, 2022).

A possible solution could be for the regulator to impose a discontinuation of paying out “premiums” when spot prices are negative (European Commission, 2023d). However, member states who tried embedding such clause in national policies had trouble in applying this to the intraday market. This due to the continuous balancing on the RTM which makes it difficult to secure one single real-time price for all market participants (European Commission, 2023d). Lastly, Schlecht et al. (2023) state some countries place a floor cap on the spot prices of 0 EUR/MWh if prices continue to remain negative for a predefined number of hours. However, the authors explain this comes with the detriment of bidding uncertainty amongst generators as they will have to guess the occurrence or duration of negative priced hours to limit their revenue losses.

Locational distortions

Schlecht et al. (2023) state another problem derived from the use of conventional CfDs, is attributable to distorted investment choices impeding the system’s efficiency. They explain that the spot price would signal generators to invest in system-friendly technologies (e.g. building solar panels west-faced to collect more energy during the afternoon) to maximize their revenues. However, Newbery (2023) states generators are incentivized by the strike price of the CfD. Herewith, the market incentives are ignored, implying generators prefer RES-E technologies correlating with the RES-E output of the construction site over technologies at least system cost. As a result, these high resource areas (e.g. sunny locations) are over favored (Newbery, 2023). An example of a good choice of location without spatial distortions (i.e., over favoring locations) could also be placing wind-generated electricity near load centers with few network requirements or wind (Neuhoff et al., 2017). This is the case in southern Germany, where electricity may also be generated when it is less windy in the northern part (Neuhoff et al., 2017).

Lacking maintenance and repowering choices

Schlecht et al. (2023) state that conventional CfDs mute the scarcity signaling function of wholesale spot prices. Further, as the duration of the CfD ends with the life of the asset, there are no incentives to increase or decline RES-E repowering investments in times of a crisis or glut (Zachmann et al., 2023). Neuhoff et al. (2023) state that in principle, it is advantageous to accelerate the restoration of RES infrastructure when electricity prices are elevated. Conversely, scheduling in maintenance is more efficient during periods of lower power prices. However, in practice, they explain that maintenance is inherently depending on weather and seasonal conditions. Further, they mention restoring for example only one wind turbine during a high price wave on the WEM, will not have a significant impact on the total plant availability.

Therefore, it can be decided that making maintenance and retrofit decisions based on short-term price distortion is less effective. Consequently, generators should prioritize efficient long-term choices, i.e., beyond the duration of the CfD.

3.5.7 Incomplete revenue risk mitigation

As mentioned priorly, conventional CfD pricing links its revenue to multiplying the price spread with the electricity output produced (see 3.5.2). Thus, the formula assumes strike prices would generate a continuous revenue stream. However, this structure does not account for fluctuations in RES-E production volume, imposing a volume risk on generators embedded within a revenue risk (Morawiecka & Scott, 2023b).

Neuhoff et al. (2023) explain that the intermittency of RES-E plants, subjected to weather conditions, can vary by more than 10% a year. Hereby, this risk of volatile production is left with the generator as mitigation by the contract structure itself is assumed to be too complex. Schlecht et al. (2023) state this risk was mitigated naturally by the scarcity pricing signaling function derived from the DAM (e.g. cloudy days implied higher prices for solar energy). However, they explain this signaling is now muted through the CfD’s strike price, imposing a risk on generators’ revenue stream. As a result, the lower volume is no longer compensated with above average prices (Schlecht et al., 2023).

Additionally, a working paper of the EU Commission on the Reform of Electricity Market Design (2023d) found that for offshore wind projects, the main concern regarding volume risk is related to lacking grid infrastructure, instead of weather variability. The generator is hereby unable to export his generated volume to the market due to a lack in transmission capacity caused by lacking grid interconnectors.

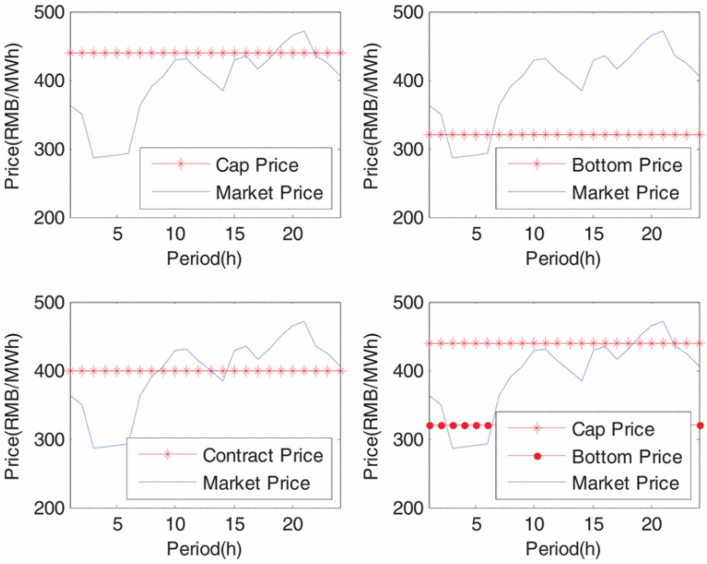
In conclusion, the impracticality of conventional CfDs in mitigating revenue risk lies in their susceptibility to volume risk, stemming from intermittent RES-E and grid infrastructure. There is a need for CfDs to provide more revenue stability in the face of fluctuating energy volumes. Neuhoff et al. (2023) provide a solution to the intermittency of RES-E. They explain how a weather hedge (which is already implemented in North America) can take away from this volume risk but comes with complex forecasting models. Further, the European Commission (2023d) proposes decoupling the payout from actual production levels through inter alia capacity CfDs or financial wind CfDs which will respectively be analyzed in section 3.8.4. Lastly, solutions to solve a lacking grid infrastructure lay rather in regulators removing permitting barriers and TSOs building out efficient maritime spatial planning regimes (Novak, 2022).

3.6 One-way versus two-way CfDs

Two-way CfDs, which are applicable to conventional CfDs explained in prior sections, are defined as the preferred mechanism acknowledging recent developments on the Commission’s proposal (see 3.2). However, following Nie et al. (2016), CfD schemes consist out of 4 types, namely: bilateral CfDs, limited price interval CfDs, one-way cap CfDs and one-way bottom CfDs. Herewith, the bilateral CfDs refer to the two-way contract structure as implemented in conventional CfDs. Within this section these four models are explained and can be visualized as follow.

Figure 5

Graphic representation of one-way cap CfDs, one-way bottom CfDs, bilateral CfDs and limited price interval CfDs



Note. Adapted from: Nie, Z., Gao, F., Wu, J., Guan, X., & Liu, K. (2016). Contract for difference (CfD) energy decomposition model for maximizing social benefit in electricity market. *IEEE*. In the public domain.

3.6.1 Double sided

In 2014, when the UK launched its first CfD allocation round, the CfDs were granted under the double-sided scheme as explained in section 3.5.1 (Department for Energy Security and Net Zero, 2023). As the EU's provisional agreement states, a preference is given to these double-sided CfDs (see section 3.2.1). The aim herewith is to both provide a hedge for the investor as well as for the consumer (Pollitt et al., 2022). Given the EU's "Fit for 55" package, the EU member states are at on one side obligated to incentivize the expeditious RES deployment (see 2.3). Further, Morawiecka and Scott (2023a) provide evidence specifically relating to onshore wind, on a two-way CfD providing the lowest LCOE in comparison to other remuneration mechanisms.

Conversely, it lays within the role of the EU to ensure consumers benefit from the advantages of cost reductions of the RES developer's learning spillover (ACER, 2022; Newbery, 2018). Hereby, it is worth exploring how to convey these benefits efficiently to consumers, without exposing them to price risk at demand side through future research. Lastly, Wild (2017) explains governments attempt to minimize their financial commitments stemming from CfDs, by opting for two-way CfDs instead of one-way CfDs.

Price corridor

However, in a study from Jansen et al. (2020) countries providing two-sided Contracts for Difference, such as the UK, Belgium, and Denmark, demonstrate an increased responsiveness to DAM wholesale prices, which is linked to uncertainty. This potentially result into elevated reference prices, which can result in energy producers seeing themselves financially contributing back to the community (Jansen et al., 2020). As a solution, the Commission's working paper on "*Reform of Electricity Market Design*" (2023d) is in favor of a price corridor opposing to a fixed strike price. Following Nie et al. (2016), these are called limited price interval CfDs. They explain that with a limited price interval CfD, there is an established upper and lower price limit. If market electricity prices surpass the upper threshold, the seller reimburses the buyer for the difference. Conversely, if prices fall below the lower limit, the buyer compensates the seller, ensuring a safeguarded revenue range for both parties (Messad et al., 2023). An example of the implementation of such cap and floor mechanism is the Spanish wind CfD auctioned in 2021 (see 4.2).

3.6.2 Single sided

Wild (2017) found that contrary to governments, RES-E project proponents are in favor of single-sided CfDs. This is linked to its higher project profitability and revenue receivable from the state. However, provides less revenue certainty (Schittekatte & Batlle, 2023a).

Lastly, CfDs can take on the format of a one-sided bottom CfD. Nie et al. (2016) explain while establishing a minimum price, the contract provider compensates the generator for the shortfall when the electricity price falls below this minimum threshold. A prime example of such mechanism is to be found Germany, namely the German market premium was implemented which consists of such a one-sided downside-cap CfD (Schlecht et al., 2023). Further, this was also the case in Belgium for its realization of offshore wind farms (Morawiecka & Scott, 2023b). The government promised to reimburse the difference between the market price of electricity and the LCOE of the

RES-E developer (Adriaen, 2023). Hereby, the minimum threshold was the LCOE. Unlike in other countries, nothing was arranged in Belgium for the scenario where electricity prices rose significantly above the LCOE. This resulted in windfall profits during the energy crisis (Adriaen, 2023). In this light, the country switched to a double-sided CfD scheme, which would avoid such wind fall profits (Morawiecka & Scott, 2023b). Hereby, Beiter et al. (2023) consider CfDs with such floor prices functionally closer to options, than to CfDs.

Due to the lack of wind fall taxes in national jurisdictions, the EU Commission imposed a revenue limit mechanism in 2022, as an emergency intervention (Cassimon & Van Den Keybus, 2023). The limit is now set at 180 MW/h, implying a multiple of strike prices set through CfD auctioning (Morawiecka & Scott, 2023b). This cap leaves a margin on the price that investors could reasonably have expected[2]. Morawiecka and Scott (2023b) explain this was done for all inframarginal technologies, which is why it was named the inframarginal rent capture mechanism.

Nie et al. (2016) explain that a one-sided cap CfD implies an upper limit price is agreed upon, by which the generator reimburses the contract provider for any amount exceeding this cap when the electricity price surpasses the agreed limit. Schlecht et al. (2023) refer to this structure as a financial call option, implemented within their “financial CfD”, which is explained in detail in section 3.8.4.

3.7 Public CfDs versus individual contract providers

Selecting a Counterparty for CfDs differs from one jurisdiction to another, carrying significant consequences for determining which entity ultimately assumes the diverse risks associated with energy procurement (Verbano & Crema, 2015). It also plays a crucial role in shaping the procurement decision-making process (Verbano & Crema, 2015). In principle, this tendering is done by a government or regulatory body. However, the CfD counterparty can also be allocated individually by multiple power sector participants, but this aspect will not be further explored within this thesis (Beiter et al.,

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[2] Council Regulation (EU) 2022/1854

2023). In the following paragraph, the reasoning underpinning the involvement of governmental entities as exclusive CfD providers on the EU WEM is explained.

3.7.1 A government entity as a credible counterparty

Conventional electricity CfDs are typically concluded between a government entity and an electricity generator (Schlecht et al., 2023). In this regard, these CfDs are often referred to as public CfDs (Schlecht et al., 2023). The reason for appointing a public entity as contract provider lays, within the previously mentioned credit risk of market participants (see 2.2.2). Simshauser (2019) states banking professionals and committees tasked with the distribution of limited loan resources display a marked preference for extensive-duration CfDs initiated by the government. This due to public CfDs containing a negligible risk of counterparty default.

3.7.2 Public centralized procurement

At supply side, Schittekatte and Batlle (2023a) explain how centralized tendering processes allow for improved coordination between generation and network expansion. They emphasize on the necessity hereof, as network access has become a scarce good in many countries. When looking at the demand side, as already explained in section 3.6.1, it is material for governments to act as a counterparty on behalf of consumers. Hereby, they grant consumers hedging from long-term price risk, allowing them to benefit from the reduced cost of RES-E technologies.

Downside of in-the-money government-backed CfDs

At demand side, Schittekatte and Batlle (2023a) state they see a trend in governments aiming to favor specific consumer groups, such as businesses or households, by assigning them as exclusive parties to RES-E CfDs. This approach discriminates the broader base of end-users from direct involvement in these agreements. Hereby, discrimination can be seen as the disadvantage of in-the-money government-backed CfDs for electricity off-takers (Schittekatte & Batlle, 2023a).

At supply side, the government takes an unhedged long position, which means it is buying electricity from generators which it will not consume itself (Schlecht et al 2023). Consequentially, this can have negative consequences on, inter alia, volatility in government revenues, rent seeking behavior (e.g. intentionally choosing low strike prices) and crowding out the forward market (i.e., contracts between generators and retailers) (Schlecht et al., 2023; Simshauser, 2019). Schittekatte and Batlle (2023ba) explain governments have the possibility to hedge themselves against long-term price risk, when having a stake in the electricity generating companies and redistribute inframarginal rents to consumers. They would then need to provide a hedge on behalf of consumers towards less risk averse market parties, creating a chain of long-term hedging contracts (Schittekatte & Batlle, 2023a). This can be exercised through trading on financial markets (Schlecht et al. 2023).

3.8 Evolved contract structures for electricity CfDs

This dissertation initially analyzed the fundamentals of conventional CfDs (see section 3.5). Consequentially, this chapter will be gradually tweaking its characteristics, ultimately leading to the development of a future-proof variant, as detailed in section 3.8.4.

3.8.1 Impact of CfDs with longer reference price periods on price risk

In a study on the development of CfD design, Morawiecka and Scott (2023b) find a Traditional-but-Smarter CfD design. They explain this CfD is still linked to volume risk and herewith revenue risk. Nevertheless, the design already provides a solution to the inconvenient hourly spot price from the DAM and disincentives production during times of negative prices. Fabra (2022b) states establishing the 'reference price' at parity with the short-term price effectively creates a fixed price contract that eliminates exposure to price fluctuations and price risk. She further explains moving away from this approach facilitates finding an optimal equilibrium between the advantages of price exposure and the drawbacks of heightened uncertainty for investors. This is a compromise that varies according to the specific attributes of the technologies involved.

Schlecht et al. (2023) explain by averaging hourly spot prices for a longer period, intra-period price differences are no longer muted for the generator implying generation incentives can be intercepted agian. Hereby, they emphasize on reference periods only providing incentives to optimize production timing within the defined reference period but not across these periods (i.e., monthly reference prices do not take into account seasonal changes in weather conditions). Further, they state the conventional CfD formula now can be updated to the below structure, with payments disbursed on moment $_t$ and e.g. the reference period of one year.

$$\text{Payment}_{\text{year}} = (\text{strike price} - \text{reference price}_{\text{year}}) \times \text{produced volume}_{\text{year}}$$

Morawiecka and Scott (2023b) explain the effect of an elongated reference period as a shift of the plant owner's focus towards a subset of high price hours, away from the lower price periods. By smoothing out volatility, intra-period price differences are more present to the generator, leading to a more optimal decision-making regarding maintenance scheduling, dispatching and investment design choices (Schlecht et al. 2023).

In the following sections this thesis illustrates this approach with data derived from the ENTSO-E (European Network of Transmission System Operators for Electricity) Transparency Platform (TP) to give away the core idea of how price risk can be mitigated through longer reference price periods. The accompanying excel retrieved from this platform is to be found in Appendix A.

Impact of a daily reference price period on spot price distortions

In this research we will derive the necessary data from the ENTSO-E TP. To take on a standardized approach, the values are each time derived from the German-Luxemburgish (DE_LU) bidding zone (BZ). To provide a clear comparison, 7 samples are taken for the month of January 2023. Samples consist of the daily average of hourly spot prices from the DAM for respectively the first week of that month, this because of visualization purposes. These values are summarized in below table.

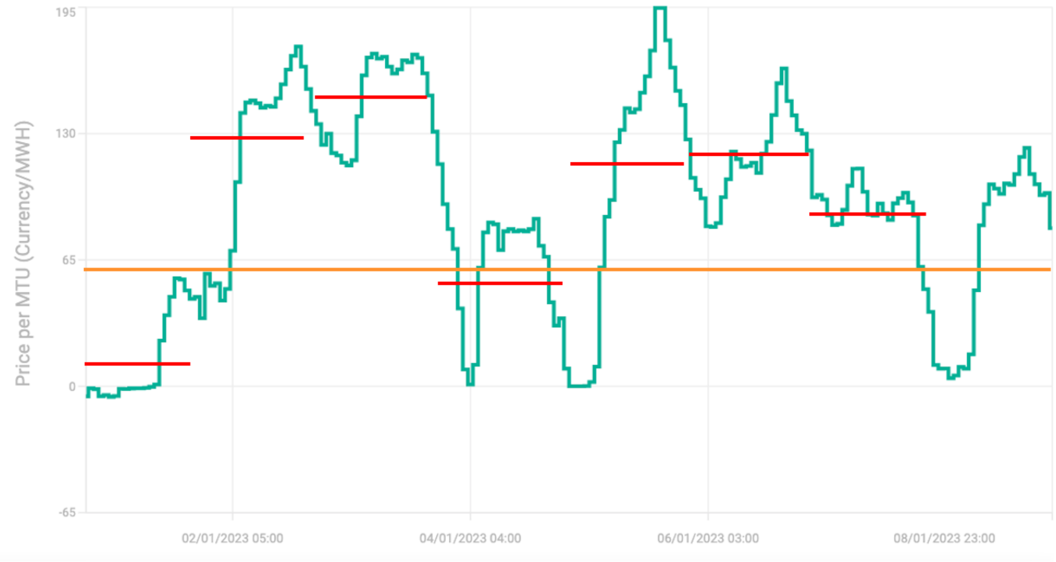
Table 1
Average spot prices (in EUR/MWh) derived from the DAM for the DE_LU BZ for the first week of January 2023

Jan '23	*1/01*	*2/01*	*3/01*	*4/01*	*5/01*	*6/01*	*7/01*
$\bar{x}$ spot price (EUR/MWh)	15.79	126.69	146.65	57.99	112.13	117.92	88.45

The set-up of a reference price period embedded in a CfD structure can now be outlined as per below graph (Figure 5), with the reference prices (marked in red) and a potential strike price of 60 EUR/MWh (marked in orange). Herewith, a smoothed reference price can be noticed for each day.

Figure 6

Hourly spot prices of the DAM for DE_LU BZ between 1/01/2023-7/01/2023



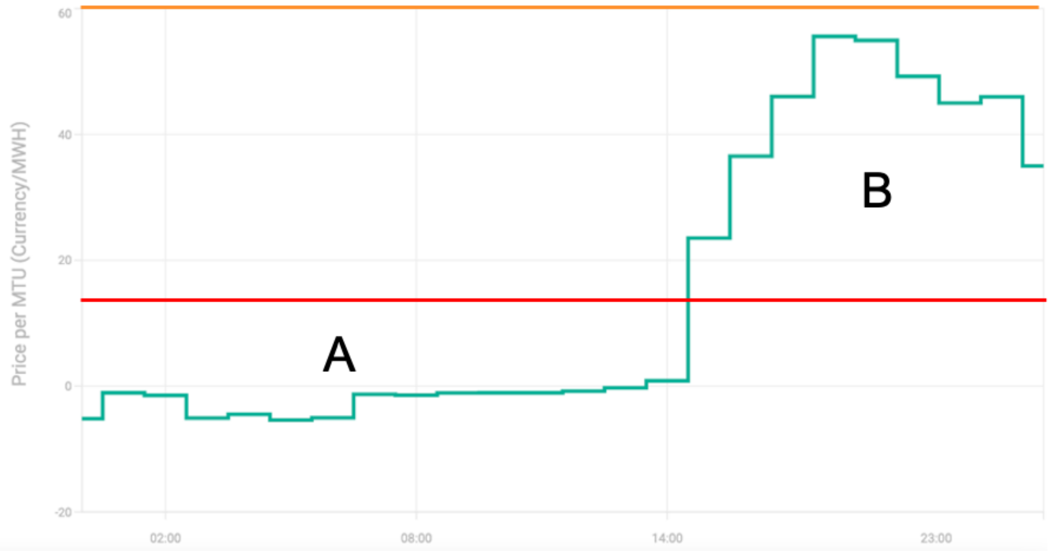
Note. Adapted from: Transparency platform. (2023, January 31). ENTSO-E. In the public domain.

For each subset of averaged time periods, the graph in Figure 5 shows the difference between the spot price (in green) and the reference price (in red). In a study of Morawiecka and Scott (2023b) they explain how these variances are either deducted from or added to the CfD strike price to form the ultimate net capture prices. When the spot price rises above its daily average, a top up from the strike price occurs when the peak within the time interval lays above the strike price. This top up implies a payout to the state, which incentivizes the producer to curtail its output (Morawiecka & Scott, 2023b). When spot prices dive under the average of that time interval a net reduction of the strike price is observed. Conducting such net capture price, incentivizes the generator to only focus on this subset its higher priced hours, while averting from low price hours. This illustrates the variability in net capture price, which is a result of “smartening” the CfD (Morawiecka & Scott, 2023b).

In Figure 6, the first subset of an averaged period (i.e., one day) can be seen more clearly. Herewith, the net price capture consists of deducting the value of area A and B from the strike price, as they both lay underneath this threshold. Further, the generator will notice the negative prices, implying a payment is required to dispatch his output. Consequently, the producer will curtail its output, despite the payouts that would have been granted out should he have chosen to dispatch (Schittekatte & Battle, 20203a). This because he is aware of a negative net capture price. Schlecht et al. (2023) state this leads to distortion of the DAM, as low-carbon generators curtail their output and unsupported fossil generators might need to continue production.

Figure 7

Overview of hourly spot prices derived of the DAM for DE_LU BZ on 1/01/2023



Note. Adapted from: Transparency platform. (2023, January 31). ENTSO-E. In the public domain.

Additionally, the implementation of a no payout rule for these negative priced hours can also be an effective incentive to output curtailment. Generators should not be encouraged through the CfD, to produce in manners that do not contribute positively to the system (Roberts et al., 2020). Hereby, a rule can be applied dictating there is no payout of payments in hours of negative prices (Schlecht et al., 2023). Further, generators are incentivized to curtail their output. As a result, balancing costs can be reduced as generators no longer maximize their output when the reference price lays below the strike price (Roberts et al., 2020). Lastly, some countries apply a threshold of six hours of negative prices before discontinuing the payouts (DEA, 2020a). However, this is argued to be inefficient as it still encourages production in negative priced hours (DEA, 2020a).

Nevertheless, it is important to note that this limits inefficiency only for zero marginal cost plants (e.g. solar PV energy) (Morawiecka & Scott, 2023b). Some intermittent RES-E plants produce at minimal variable costs above 0 EUR/MWh, such as wind energy which runs by a variable cost of €5–12/MWh (Schittekatte & Battle, 20203a; Newbery 2023). As these generators would generate more output, their variable (and presumably marginal) costs would increase, which causes prices to decrease, resulting in more frequent zero market prices. For them, this rule might be an excessive measurement since modest variable costs could be adequate to achieve the same objective more effectively (Morawiecka & Scott, 2023b). Therefore, it is once again important to tailor the CfD design to its RES-E technology specifications (Schittekatte & Battle, 20203a).

Lastly, Morawiecka and Scott (2023b) explain that when an approach of net capture prices leads to a net capture price of 0 EUR/MWh, this can incentivize the plant owner to go offline and schedule in maintenance hours. However, this net zero capture price might happen in a period of high prices, creating an opportunity cost for the generator (Schittekatte & Battle, 20203a). Thus, following these authors this approach leads potentially to maintenance scheduling distortions. On the contrary, Schlecht et al. (2023) state that decisions-making regarding scheduling in maintenance hours is less distorted because of a longer reference period. This is due to generators being incentivized again to capture the highest prices as intra-period references are no longer muted. This contradiction can be declared by nuancing the term “longer” reference period. Neuhoff et al. (2017) explains these intra-reference signals are indeed incentivized when annual averages are set. However, with monthly averages set as the reference price, generators are not aware of longer high price periods, thus look only at the subset or net capture price as Morawiecka and Scott explained previously.

In conclusion, despite still creating distortive price signals, implementing a longer referencing price period within the CfD’s design incentivizes generators to be more market responsive to the day-ahead market. Hereby, this design leaves room for improvement.

Monthly, seasonal, or annual reference price periods

Fabra (2022a) explains implementing the average of an extended price period as a reference price, is called a CfD with a sliding premium or a flexibility contract. Herewith, different lengths of reference price periods serve different types of RES-E technologies, allowing a higher or lower level of price exposure to the plant owner (Fabra, 2022b). Hereby, a distinction should be made between intermittent and base load RES-E technologies (Fabra, 2022b).

For intermittent RES-E technologies, like solar and wind power, a monthly average of the spot price is preferably chosen as the reference price (Fabra, 2022b). Conversely, Bowden (2023) states that the reference price is set at an hourly rate for these types of technologies. Herewith, plant owners are exposed more to price risk. This can incentivize them to higher responsiveness in the balancing markets for generating additional revenues, leading to less intraday price distortion (WindEurope, 2022; see *Price distortion on the intraday market*).

Non-intermittent, base load RES-E technologies, such as hydropower, biomass, and biogas, produce power at a constant rate and are not designed to respond to (off-)peak demand triggers (Fedkin, n.d.). Herewith, a different approach should be considered when determining the reference period. Bowden (2023) explains baseload CfDs are set at a seasonal reference price period of six months. To give a concrete example, for deliveries in the period from 1st April to 30th September 2023, a reference price is based on the average of all operating days between 1st October 2022 and 31st March 2022 (Bowden, 2023). Hereby, generators focus on longer intra-period differences, leading to less market responsiveness compared to intermittent RES-E technologies. Schlecht et al. (2023) explain that this is due to reference periods only providing incentives to optimize production delivery within but not across these periods. As a result, longer periods contain more seasonal incentives than e.g. monthly periods.

However, the Danish hybrid wind CfDs also contain a yearly average of spot prices as the reference price (see 4.1). Although this might not be most efficient given the nature of intermittent RES, the Danish regulator still chose this method to be able to forecast their yearly budget more precisely for these 1GW wind farm projects (DEA, 2020b). Further, in the Netherlands this yearly average is also used within wind CfDs (Neuhoff et al., 2017). Neuhoff et al. (2017) explain this is because the yearly average of spot prices captures all incentives for system-friendly investment decisions. On the contrary, when moving to a monthly average as reference price period, they state incentives to drive up production in periods of high prices are lost. However, when it comes down to maximizing system-value by designing system-friendly installations, these incentives remain within the period of one month (Neuhoff et al., 2017).

Even with a clearer and more effective signal from electricity prices, it's likely that project developers will only partially incorporate these trends into their investment decisions. This due to a guaranteed strike price for the output sold on the WEM (Neuhoff et al., 2017). Herewith, payments are still influenced by the generated volume of the plant. Therefore, the European Commission suggests implementing a reference volume, which can be actioned under the format of, inter alia, capability based CfDs and financial CfDs (European Commission, 2023d). Additionally, Newbery (2023) proposes his yardstick CfD to mitigate this volume risk.

3.8.2 Capability-based CfDs

In previous sections, the payments, CfDs disbursed were always based of the price spread multiplied with the output (see 3.5.2 and 3.8.1). In this light, the volume risk and the resulting revenue risk are not hedged as generators can still manipulate prices and herewith payments through their own output. Fabra (2022a) states if it lays within the ability of generators to influence the average price with their own production, they will choose to overproduce. This overproduction leads to price cannibalization which drives the reference price to sink below the strike price (Jomaux, 2023). Hereby, generators exercise influence on receiving the premiums (i.e., payouts) they receive (Fabra, 2022a). However, Newbery (2023) states that when generators are unable to excess market power and influence prices, they offer their output on the market according to the true avoidable costs (i.e., limiting (modest) variable costs derived from excess production through production curtailment).

In a Capability-based CfD, the underlying volume determining the payment is based on the expected generation rather than on actual generated output (European Commission, 2023d). Hereby, spot price exposure is no longer distorted as, the quantity of production included in the CfD is based on factors that the generator bound by the contract cannot control (Schittekatte & Batlle, 2023a). This decoupling between the asset its production and its payments can now be described through below adjusted formula (Schlecht et al., 2023).

$$\text{Payment}_t = (\text{strike price} - \text{reference price}_t) \times \text{production potential}_t$$

To predetermine the generated output, a benchmark, linked to the RES-E technology, is set through the potential production of the considered generator (Jomaux, 2023). This benchmark consists of calculating the average production value of all other installations within the predetermined reference period (Neuhoff et al., 2017). As an illustration, for a CfD supporting a solar power plant in Belgium, the average solar production in Belgium can serve as the reference volume for weighing the CfD’s spread (Jomaux, 2023). Morawiecka and Scott (2023b) add to use the data of all generators with the same installations, this should be provided by the technology’s equipment manufacturer. They state that even though these innovations introduce additional complexity, the problems they create, can still be overcome, or managed (by e.g. sharing know-how to stakeholders) and should not halt progress as it is still considered a successful approach.

Nevertheless, in a response from ENTSO-E to the European Commission’s public consultation, the calculations behind this capability-based CfD should be more refined and herewith more complex (ENSTO-E, 2023). ENTSO-E states the reference volume is based on the volumes that “could” be produced by the installation. These are determined by not only the technical characteristics, but also the local weather conditions related to the specifications of the applied technology (ENSTO-E, 2023). Schlecht et al. (2023) add that this approach is susceptible to manipulation through the production potential calculation model, as its calculation contains high commercial relevance for manufacturers. However, Schlecht et al. 2023 state it is the sole adjustment in designing CfDs that effectively allows for the elimination of dispatch inefficiencies concerning intraday and balancing markets. Hereby, they explain, the decoupling of payments from actual production addresses the root of the intraday dispatch distortions as described priorly (see *Price distortion on the intraday market*).

Conversely, Schlecht et al. (2023) state that implementing a reference volume still mutes the price signal incentivizing efficient investment (i.e., system-friendly) and retrofitting decision-making process, as it still relies on the individual asset’s production potential. This implies that by focusing only on the production potential of individual technologies, without comparing them to others, the impact of price signals incentivizing (re)investment is still muted. Additionally, they state the impact of this design on maintenance scheduling remains unclear.

Lastly, Schittekatte and Batlle (2023a) emphasize on the consequence of implementing such fixed-quantity contract, namely the need for technological specific auctions (i.e., single asset type auction (see section on *Competitive price setting*)), as not every technology provides the same capacity output. However, the 10-year national energy and climate plans (NECPs) which details the plans of European Union member states to achieve the EU's energy and climate goals for the year 2030, already cover this fact. (European Commission, n.d.-b). Thus, within these plans, only technological-specific auctions are planned out.

3.8.3 The yardstick CfD

Newbery (2023) proposes a yardstick CfD as a mechanism designed to address challenges specifically relating to wind and solar power generation. Hereby, this innovative design offers a solution to location and dispatch distortions (Schlecht et al. 2023). This type is a form of a capability-based CfD, implying it also decouples payments from generated output, as explained in the previous section (Schlecht et al. 2023). However, the yardstick CfD provides a tweak which enables the CfD to discriminate in favor of those installations which market value is larger (Barquín et al., 2017). Hereby, this design provides a solution for the inability of the capability-based CfD’s in incentivizing efficient system-friendly, investment decisions.

As already explained prior to this section, a significant issue in renewable energy is the locational distortion (Schlecht et al., 2023). When the contract's strike price is higher than the average market price (or the premium is positive), there is an extra motivation to establish intermittent RES plants in areas with strong winds or abundant sunshine (Newbery, 2023). This is due to output maximalization because of unrestricted payouts, without considering the impact on the grid (Newbery, 2023). The yardstick CfD should incentivize the generator to invest in locations that provide intermittent RES at the lowest overall system cost, including investment and transmission expenses (Newbery, 2023). Additionally, Newbery (2023) states the prohibition of negative prices should also be embedded within the yardstick CfD to discourage dispatch distortions.

Forecasting output

The market value of electricity can be increased through efficient technology and siting choices (Newbery, 2023). The yardstick CfD determines this value through site-specific production forecasts, instead of the production potential calculation model implementing all data of identical technology generators of a jurisdiction (Newbery, 2023).

Newbery (2023) explains to conduct such value, for each contracted hour, the amount is based on the predicted production of a specific intermittent RES technology (i.e., wind or solar energy). Hereby, the unit of measurement would be output/MW, which implies MWh/MW. Herewith, he explains the length of the contract should not be predetermined by years but rather by full operating hours (MWh/MW capacity). Hereby, Morawiecka and Scott (2023a) explain that that this hedges the revenue risk, however the duration hereof remains unclear.

The predictions of this output volume are based on the local weather forecasts for wind and solar energy. Newbery (2023) explains such local forecasts enable the generator to opt for a certain hourly predicted output within a future timeframe. The chosen forecasted data is then communicated to the counterparty (the government entitiy) through power curves derived from this data. Afterwards, the generator has to sell its output at or shortly after the time of the forecasted data. Therefore, there is only a slight deviation possible between the output contracted and output sold (Newbery, 2023). Given the output is forecasted and send out on beforehand to the other contract party, a competitive generator is unable to influence the market price. Hereby, bidding according to the true avoidable cost (i.e., modest variable costs of wind energy) is a dominant strategy (Newbery, 2023).

Locational Marginal Pricing

Hereby, the Yardstick CfD can correct locational distortions, in combination with long-term transmission contracts (Newbery, 2023). It ensures efficient location by taking into account the predicted output-weighted locational marginal prices (LMPs) (Newbery et al., 2018).These LMPs calculate the costs regarding congestion and electricity loss for supplying the grid with electricity in at a certain node (Newbery et al., 2018) This nodal pricing incentivize generators to set up in locations that are beneficial for the overall system, not just for individual resource availability, so they can operate at the least avoidable cost (Newbery, 2023).

By aligning the contracted volume in any hour to the developer's hourly forecast output, the Yardstick CfD helps in managing congestion and curtailing excess generation. This approach ensures that generation is more closely aligned with grid needs and market demands, thus reducing the need for curtailment of renewable energy and better managing grid congestion (Newbery, 2023). Nevertheless, the EU repeatedly wrote off LMP due to being unsupportive to market liquidity and market depth and costs outweighing the benefits (ENTSO-E, 2021). Morawiecka and Scott (2023a) add that Newbery's approach is rather complex to determine, which drives up implementation costs. Conversely, Newbery (2023) revealed substantial evidence proving the opposite and states some countries like the UK are already considering shifting towards such method.

Lastly, the Spanish regulator embedded such mechanism already in its Royal Decree 413/2014), albeit implemented with a tweak, namely a reference plant instead of a predetermined output (Schlecht et al., 2023; see 4.2).

3.8.4 Financial wind CfD

This section explains the concept of financial wind CfDs, hereby arriving at the last tweak in reaching the optimal CfD design following Schlecht et al. (2023). It is considered to be a two-way capability-based CfD (Schittekatte & Batlle, 2023a).

However, its design still differs from the yardstick CfD by Newbery. Schlecht et al. (2023) state that this instrument is tradeable, thus it moves away from the CfD's asset-dependent structure. They declare, this is the sole design which is able to mitigate the revenue risk caused by the intermittent nature of RES-E technologies, as it tackles both price and volume risk. Hereby, the CfD is specifically focusing on the support for wind farm generators. However, Hirth (n.d.) emphasizes on the possibility to implement this design for solar energy producers as well. Further it is as well applicable for dispatchable plants (Schlecht et al., 2023).

Altered and standard specifications

The financial CfD consist of a competitive auctioning process to tender these financial contracts. Schlecht et al. (2023) explain the auctioned volume (i.e., awarded capacity over concluded contract(s)) can be determined prior to the auction. However, they state implementing a demand curve forms the better alternative. A demand curve can reduce market power, potentially prompting governments to procure increased volumes of contracts in scenarios where there is an abundant supply at lower prices (Schlecht et al., 2023). Conversely, they are more likely to diminish these volumes when electricity supply is limited, and prices are elevated (Schlecht et al., 2023). Additionally, the contract durations is determined at 20 years, and payments are fixed, and is inflation-indexed (Schlecht et al., 2023).

Disbursement method

Financial CfDs operate as a mechanism where the producer receives a consistent monthly payment stream (European Commission, 2023d). Concurrently, the producer reimburses the government with the revenue generated from the spot market for that month (European Commission, 2023d). Schlecht et al. (2023) emphasize on the fact that these distributed revenues are not stemming from an actual asset, but instead are derived from the reference wind farm (see below).

Payment structure

Schlecht et al. (2023) explain the payment's calculation is based on the hourly spot price rate. The government provides a stable, hourly compensation to the generator, which is not contingent upon the actual production during these hours. The rate of this hourly compensation is established through competitive bidding in the initial procurement auction (Schlecht et al., 2023). Hereby, there is no competitive strike price determined. Further, the choice of an hourly rate constitutes a crucial element in the structure of the financial CfD, as the effectiveness lays within the production of the individual asset closely aligning with that of the reference generator (Schlecht et al., 2023).

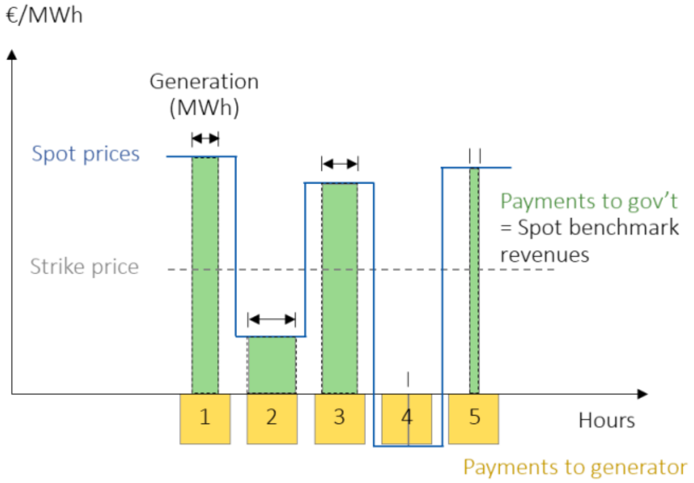
The generator's payback ($_{g}$) to the government consists of the hourly revenues stemming from a benchmark generator. These revenues are calculated as the difference between the day-ahead spot price and the benchmark operational costs, multiplied by the hourly ($_{t}$) output of the reference generator (Schlecht et al., 2023). The payment formula can now be updated as follow.

$$\text{Payment}_{g,t} = (\text{day-ahead spot price} - \text{benchmark operational costs}_{t}) \times \text{production of reference generator}_{t}$$

This equation goes up when the difference is positive; otherwise, the profit is zero. For wind and solar energy, where operational costs are negligible, profits are essentially equivalent to revenues (Schlecht et al., 2023). Notably, it is not the specific asset's hourly output that serves as the collateral for the contract. This second form of payment essentially acts as a one-way upside-cap CfD, which the authors refer to as a financial call option. Additionally, the strike price is administratively set at the benchmark operational costs, which is (near) zero for wind and solar energy sources (Schlecht et al., 2023). Figure 8 visually represents both the dual payment structure (left side) and the resultant revenue flow (right side).

Figure 8

Visual representation of the financial wind CfD



Note. Adapted from: Schlecht, I., Maurer, C., & Hirth, L. (2023, January 25). Financial contracts for differences. In the public domain.

Defining a theoretical reference turbine and its production metrics

Schlecht et al. (2023) deliver three possible methodologies to determine the reference turbine for intermittent RES-E technologies. Further, they provided two approaches for dispatchable plants. However, these two remain out of scope within this thesis and provide herewith an incentive to explore future research on the implementation of CfDs for non-intermittent generation support.

Mathematical forecast model

This approach entails the use of a mathematical model to estimate the output of a reference turbine. The model relies on measured, regionally aggregated weather data, which is similar to the approach of the yardstick CfD by David Newbery. While such an approach offers a broad-based hedge against variability in individual turbine performance, it does contain some limitations.

The average of a large region's weather data may not provide a precise hedge for specific turbines but offers a generally adequate risk mitigation for numerous plants (Schlecht et al., 2023). The primary advantage lies in its independence from the operational decisions of individual power plants, which might be strategically influenced

(Schlecht et al., 2023). However, this method introduces significant risks related to the reliability and stability of weather measurement techniques. Any changes in these techniques or intentional manipulations by strategic entities could have substantial financial consequences due to the model's heavy reliance on weather data (Schlecht et al., 2023).

Utilization of Existing Wind Power Plant Data

This methodology proposes selecting a sample of actual wind power plants to define the reference turbine. However, this approach is susceptible to potential manipulation, particularly if the sample size is small (Schlecht et al., 2023). The incentives to influence the dispatch of these reference plants could undermine the validity of this method, making it a less feasible option for accurate benchmarking (Schlecht et al., 2023).

Aggregate Output-Based Methodology

The third option suggests using the cumulative output of all wind turbines within a specific country or market zone. This method would mirror the 'market value' concept prevalent in certain existing support mechanisms in Germany, though it necessitates a shift from an energy-based definition (EUR/MWh) to a capacity-based one (EUR of revenue /MWh). The advantage of this approach lies in its resistance to manipulation due to the extensive number of wind turbines involved. This method is similar to the capability-based CfD methods explained in section 3.8.2.

In conclusion, central to the concept of the reference turbine is its role as a benchmark for production and revenue, which is independent of the production of any individual asset. This independence is critical to mitigate the distortive effects observed in other CfDs. Simultaneously, it is essential for the reference turbine to maintain a high correlation with individual assets, ensuring its effectiveness as a financial hedge instrument. However, as they declared to have determined the most efficient CfD design, two in three methodologies of defining the reference generator were based on design implications from both the yardstick CfD and the capability-based CfD.

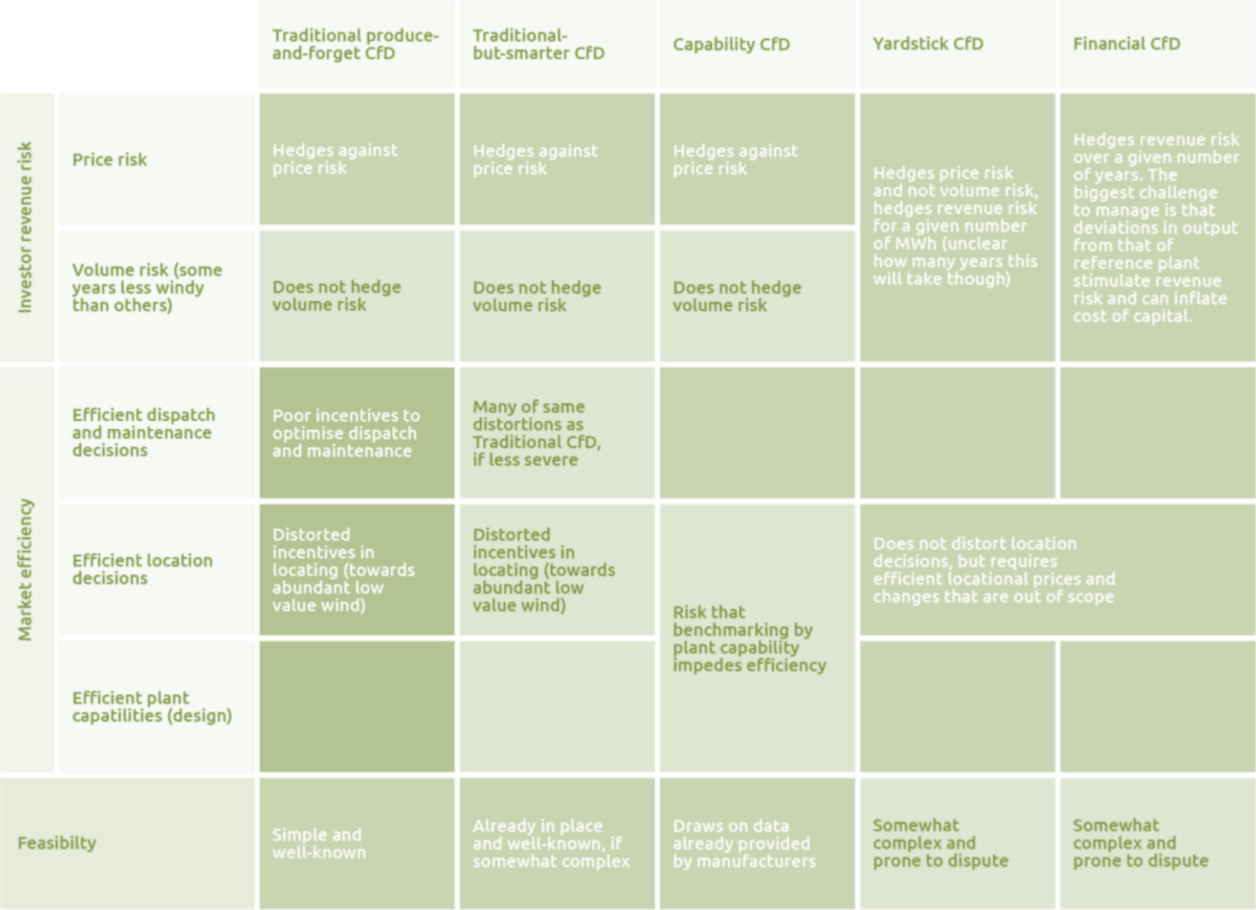
Criticism on the financial CfD model

Morawiekca and Scott (2023b) argue that the hourly spot price as an essential element is susceptible to output deviations. Hereby, it will be challenging to manage the difference between output from the reference plant and the output from the actual plant, which is sold on the DAM. They state this could eventually lead to a revenue risk and a rise in CoC as uncertainty is embedded within this approach. Additionally, they express their concerns on the complexity of the design and state it could give reason to dispute. Further, Moerenhout et al. (2023) highlight this CfD design has not yet been applied in any jurisdiction, which turns it into a purely academical approach. Hereby, it is important to explore further research on the recommendations brought forth by this CfD. Further, the authors state they foresee the short-term implementation feasibility very negatively. On long-term feasibility they remain neutral, as it could go both ways. Lastly, they find this design contains a high administrative complexity.

To summarize the adjustments made throughout this chapter, the below overview can be presented (Figure 9). Herewith, it can be concluded that although specific technologies require a specific approach, the financial CfD scheme is the most capable design in mitigating all distortions derived from revenue risk (i.e., price and volume risk). This conclusion should be considered with the appropriate due diligence as the model is at its theoretical stages. Herewith, when this contract will come into practice within the upcoming years, further research should be established on the effects of implementing the financial CfD for various RES-E technologies.

Figure 9

Overview of discussed CfD design implications



		Traditional produce-and-forget CfD	Traditional-but-smarter CfD	Capability CfD	Yardstick CfD	Financial CfD
Investor revenue risk	Price risk	Hedges against price risk	Hedges against price risk	Hedges against price risk	Hedges price risk and not volume risk, hedges revenue risk for a given number of MWh (unclear how many years this will take though)	Hedges revenue risk over a given number of years. The biggest challenge to manage is that deviations in output from that of reference plant stimulate revenue risk and can inflate cost of capital.
	Volume risk (some years less windy than others)	Does not hedge volume risk	Does not hedge volume risk	Does not hedge volume risk		
Market efficiency	Efficient dispatch and maintenance decisions	Poor incentives to optimise dispatch and maintenance	Many of same distortions as Traditional CfD, if less severe			
	Efficient location decisions	Distorted incentives in locating (towards abundant low value wind)	Distorted incentives in locating (towards abundant low value wind)	Risk that benchmarking by plant capability impedes efficiency	Does not distort location decisions, but requires efficient locational prices and changes that are out of scope	
	Efficient plant capatilities (design)					
Feasibilty		Simple and well-known	Already in place and well-known, if somewhat complex	Draws on data already provided by manufacturers	Somewhat complex and prone to dispute	Somewhat complex and prone to dispute

Note. Adapted from: Morawiecka, M., & Scott, D. (2023a, December 18). Contracts for Difference – RAP Blueprint. RAP Power System Blueprint. In the public domain.

4 COMPARATIVE CASE STUDY: CHALLENGES AND LESSONS LEARNED FROM THE IMPLEMENTATION OF CFDS IN THE DANISH AND SPANISH ELECTRICITY MARKET

In this chapter, we delve into a comparative analysis of the Danish hybrid wind CfD and the Spanish wind CfD, building on the prior discussions of long-term market price risks and CfD design mechanisms. This study contrasts these distinct European models, focusing on their alignment with policy goals, and defining their operational nuances such as the reference price period and auction design. Herewith, this thesis aims to understand how different approaches can reduce RES-E investor's uncertainty in mitigating long-term price risk through CfDs.

4.1 A Danish hybrid CfD for the Thor Offshore Wind Farm

With its 2018 Energy Agreement, the Danish ministry of Climate, Energy and Utilities (KEFM) published the target of providing the nation with offshore wind electricity for 55% of its total energy needs by 2030 (KEFM, 2018). Herewith, an increase in RES-E projects is required. The Danish regulator decided herewith to establish three offshore wind farms in Danish waters, before 2030 (Larsen & Kitzing, 2020). Larsen and Kitzing (2020) state out of these three, the Thor Offshore Wind Farm (TOWF) will be the largest offshore wind farm in Denmark with a capacity between 800 and 1000 MW. The project is expected to go in full commissioning in 2027.

4.1.1 The Thor tender

The Danish Energy Agency (DEA) (2020c) published a report stating that on the 22nd of June 2020, the Danish regulator decided on a technology-specific auction using a two-way CfD structure to deliver the TOWF. The CfD is hereby considered to be auctioned through a single asset CfD auction (see section 3.5.3). Additionally, developers' submitted bids are capped at 34 EUR/MWh, with no bids accepted above this threshold. This implies a tendering process with bids capped off at the highest accepted bid, allowing the possibility of manipulating the strike price (see section 3.5.4).

The hybrid Danish CfD establishes limits on the financial contributions from both the Danish Government to the project developer, and from the project developer to the Danish Government (TED, 2020). Payouts throughout the CfD's duration can only amount to a maximum of 870 million EUR (2018 prices) (Jensen, n.d.). Hereby, the CfD's duration is secured on 20 years (Larsen & Kitzing, 2020). The maximum value of paybacks by the developers was set at 375 million EUR (2018 prices) (Jansen et al., 2022). Herewith the DEA made the following statement in its tender materials, which was deleted after the tender took place (Gallagher & Jørgensen, 2021):

> *"Caps are set at a level so high that with the current electricity price forecasts the DEA does not deem it likely that the caps will be reached."*

These payments are settled monthly, paid out by output unit per hour or in kWh multiplied with the difference between the average of the electricity price the previous year and the bid price (Larsen & Kitzing, 2020). As these payments are weighted by volume, there is a revenue risk present implying e.g. low volumes are no longer signaled as scarce, thus do not receive a higher price (see section on *Incomplete revenue risk mitigation*).

4.1.2 Referencing period

Larsen and Kitzing (2020) explain how the reference price is set annually based on the previous year's average spot price of the BZ DK1 as determined on Nord Pool. Herewith, Nordpool is the Nordic Energy Exchange market (DEA, 2020c). Opting for a yearly average as reference price differs from the traditional hourly-based CfD approach used for other offshore wind farms in Denmark. Therefore, the generator is capable of better decision-making regarding maintenance schedules, less focused on output maximalization and more incentivized to opt for investment decisions at least system cost (see section on *Locational distortions*). A Q&A report of DEA (2020b) on "Prior Information Notice for Thor Offshore Wind Farm" adds that the wind farm concession owner is hereby incentivized to maximize the market value of the delivered electricity. Further, the Danish regulator is hereby able to plan out their budgeting more precisely. Lastly, a no payout rule was implemented as of the first hour with non-positive prices (DEA, 2020a). Hereby, the CfD refrains from the 6-hour threshold, as this would encourage production even when the market price is negative (DEA, 2020a; see *Impact of a daily reference price period on spot price distortions*).

Despite these advantages, the effect of the annual reference period on price volatility cannot be analyzed as payment transactions only start after the first kWh is placed onto the grid, with the first kWh expected in the second quarter of 2024 (Larsen & Kitzing, 2020). Additionally, Chapter 4.1.4 covers the reason to why future research on the reference price of the Danish hybrid CfD will no longer be relevant for the 2021 allocation round on the TOWF project.

4.1.3 Strike price

The strike price is determined through a competitive price setting, as outlined in 3.5.3., with the offer submission deadline for potential developers was set within the fourth quarter of 2021 (DEA, 2022). Following the tender awarding procedure developer's bids were ranked based of the lowest submitted bid price, hereby following the reverse auction design (see section 3.5.3; Larsen & Kitzing, 2020). Out of the submitted bids, the lowest bid price came out to be 0.01 øre/kWh (approx. 0.0134 EUR/MWh in 2021)[3], which would serve as the strike price (i.e., if not altered in the negotiation phase (see section on *Competitive price setting*)) (Gallagher & Jørgensen, 2021).

Larsen and Kizting (2020) explain in situations where multiple bids shared the same price and are the best offers (i.e. the lowest price), the bid with the greater capacity (measured in megawatts, MW) would be selected. If, however, there were several identical bids in terms of both price and capacity that stand as the best offers, the winning bid would be determined through a random lottery process. Herewith, the latter was indeed the case with 5 bidders (Ørsted, CIP and Andel, Total Energies and Iberdrola, Vattenfall, RWE) bidding 0.1 øre/kWh for the full auctioned capacity volume of 1GW (Gallagher & Jørgensen, 2021). Through random lottery, RWE came out as the winner of the auction awarded with a 20-year CfD contract.

4.1.4 Winning bidder

Plechinger (2021) states the DEA claimed is as a big success as it would be the first time that establishing an offshore wind farm requires a payment to the state in obtaining the required authorization. However, Gallagher and Jørgensen (2021) explain it is not

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[3] From: https://www.oanda.com/currency-converter/en/?from=EUR&to=USD&amount=1

ought to be apparent for a bidder to be interested in accepting such contract. The DEA forecasted that with a near-zero strike price and the future relevant market prices, it would only take the developer 3 years until the payback cap of 375 million would be reached (Gallagher & Jørgensen, 2021). As a consequence hereof, the CfD would be fulfilled after 3 years, and the winning bidder will as of then be able to retain the revenues from any further production at the market price. This leaves the CfD contract merely as a 375 million offer to be authorized to realize the TOWF (Gallagher & Jørgensen, 2021). Hereby, Gallagher and Jørgensen (2021) add that appointing a winner through a lottery goes against letting competitive forces play out the outcome and thus against the purpose of setting up an auction in awarding the CfD(s).

Although price risk could not be determined in this case, this assessment encourages future research on analyzing the efficient magnitude of payback caps. Ideally, this would be without imposing a strain on developers of losing above-average revenues in periods of persistent high prices. Further, there should be an alternative strategy to prevent extremely low bids from becoming the strike price throughout the contract period, as this causes generators to submit bids below their CoC.

4.2 Spanish wind CfD

Although Spain was a pioneer in providing RES support embedded within its national legislation. The first CfD auction only occurred in 2021. Herewith, the following sections provide context to the Spanish electricity market design, as well as examine the CfD's implications.

4.2.1 Overhaul of the Spanish electricity market design

In 2013, the Spanish regulator proposed a radical overhaul of the design of its electricity market (Barquín, 2014). The reason hereto was due to its original system being economically unsustainable. This previous system passed the energy costs directly through to the end-consumer (Barquín, 2014). Hereby, RES was supported by FiTs leading to excessive support costs, which left a loss as big as the tariff deficit resulting from access costs (e.g. these RES support costs). This incurred loss was stemming from the access tariff (i.e., remuneration for inter alia, network costs, RES support, ancillary services, …) being set too low due to political grounds. As politicians were sensitive to passing through these costs to the consumer given the unfavorable economic environment (Barquín, 2014).

Given these challenges, the Spanish government implemented *regimen retributivo específico*, which outlined how it would optimize its RES support mechanisms by implementing a fixed output contract and appointing a reference plant benchmark (El MITECO, n.d.; Huntington et al. 2017). Herewith, amongst other measures, the scrapping of costly FiTs was implemented accordingly (López, 2013). Further, the scheme was directly implemented within its national legislation, in disregard of requesting the EU Commission's approval. Hereby, the regime was considered as state aid as it is a direct grant and had to be evaluated against the EU's state aid rules by the Commission, which was later approved[4].

This context shows how Spain was a pioneer in supporting RES deployment especially for offshore wind farms, which was already expressed in 3.3.2. However, it was only as of 2020 when Spain introduced its first CfD scheme (Roldán-Fernández et al., 2021). This was due to the EUs guideline on NECPS imposing Member States of drawing out a plan in achieving the preconceived RES-E targets by 20230 (Roldán-Fernández et al., 2021; see 3.8.2). However, this new regime is not compatible with the former support scheme (European Commission, 2020).

4.2.2 Contract design of the Spanish wind CfD

In 2020, the implementation of Real Decree 960/2020 introduced a novel compensation framework for renewable energy sources (RES), utilizing a tender-based system within the CfD's design (Roldán-Fernández et al., 2021). The primary aim of this tender process was to establish cost-effective support levels for various RES technologies. Herewith, it is marked as a technology-neutral auction (see *Competitive price setting)*.

Auction design

Under the CfD structure, wind farms are required to reimburse when the market price surpasses the auction price (Roldán-Fernández et al., 2021). Conversely, the

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[4] C(2017) 7384. State aid SA.40348 (2015/NN).

government compensates when the market price falls below the auction price (Roldán-Fernández et al., 2021). Moreover, his regulatory framework incorporates a system of minimum and maximum bid limits, essentially establishing price caps. Bids exceeding the maximum threshold are disqualified to encourage cost-conscious bidding. Similarly, bids below the minimum limit are also rejected (Roldán-Fernández et al., 2021). All eligible bids falling within these price caps are then organized in ascending order until the predetermined volume limit of the tender is fulfilled. Hereby, the price corridor was determined in a cost-effective manner because it was set by a competitive process. Additionally, this cap and floor structure describes the implementation of a price corridor or a limited price interval CfD (see *Price corridor*).

The 2021 government Contract for Difference (CfD) auction resulted in an average strike price of 24.47 EUR/MWh with the lower bound 14.98 EUR/MWh and the highest accepted bid being the upper bound of 28.9 EUR/MWh (Claußner, 2021). These contracts are awarded for a 12-year period (Morawiecka & Scott, 2023a). This price, notably lower than the market price of 2021, reflects the inclination of investors to forgo immediate profit potential in favor of long-term price stability, which is the aim of implementing a CfD (Peinado et al., 2022). Claußner (2021) states the reasoning behind this behavior can be found in generators observing a higher decrease in CoC with CfDs in comparison to commercial agreements like PPA's. Herewith, the investing generator is willing to accept a lower strike price.

Nevertheless, the CfD is based on the hourly DAM as the reference price. This incentivizes intraday distortion and leads to the issue of produce-and-forget with its corresponding distortions (see section 3.5.5 and 3.5.6). Herewith, it would have been more optimal to choose a longer reference price period, like the Danish CfD opting for an annual average of the reference price.

Output restriction

Further, Claußner (2021) explains the Spanish regulator opted for a more flexible contract regarding the actual output of the generator. Hereby, generators are not obliged to sell their whole output under the CfD, but instead only a defined amount. Tang (2021) explains upon reaching the corresponding specified threshold, electricity producers have the option to either continue selling their power under CfD up to a predetermined limit, or they can choose to enter the merchant market with this residual production. Going merchant can be achieved by concluding commercial agreements such as PPAs, enabling investors to potentially sell their output at a higher price (Claußner, 2021). This approach perfectly addresses the concerns expressed in section 3.2.1 on allowing some level of merchant risk into the contract. However, it is still important to do future research on determining the ideal output threshold to determine the optimal generation output supported by the CfD contract.

In comparison to the Danish CfD, this CfD design leaves investors with some slack on implementing a flexible hedging strategy and hereby maximize returns on their generation. When looking at the Danish CfD, this could have prevented the effect of investors turning the CfD into a purely financial obligation consisted out of paybacks only.

4.3 Summarizing overview

4.3.1 Danish Wind CfD (Thor Offshore Wind Farm)

Advantages

- Encourages development of offshore wind farms with a focus on meeting national energy targets.
- Offers a 20-year duration for CfDs, ensuring long-term stability for developers.
- Caps on financial contributions and paybacks create limits to government and developer liabilities.
- Annual reference price setting allows for better planning and decision-making for maintenance and investment.
- Incentivizes maximizing market value of electricity produced.

Disadvantages

- Caps on bids can potentially lead to manipulation of the strike price.
- Random lottery for awarding contracts could undermine competitive pricing.
- The effect of the annual reference period on price volatility is not yet clear.

- Payback cap may limit the long-term benefit for developers in periods of high prices.

Differences compared to the Spanish Cfd

- Utilizes a single asset CfD auction design.
- Implements an annual reference price setting, unlike the traditional hourly-based approach.
- Has a specific focus on offshore wind farms.

4.3.2 Spanish Wind CfD

Advantages

- Radical overhaul of electricity market design aimed at economic sustainability.
- Technology-neutral auction design encourages a broader range of technologies.
- Price corridor set by competitive process ensures cost-effective support levels.
- Allows generators to sell a defined amount of output under CfD, with the option to go merchant with residual production.

Disadvantages

- Original system led to excessive support costs and tariff deficits.
- Hourly reference price may incentivize intraday distortion and distortions derived from the issue of produce-and-forget.
- Uncertainty about the ideal output threshold for optimal CfD support.

Differences compared to the Danish CfD

- Introduced a novel compensation framework in 2020, much later than Denmark's support for offshore wind farms.
- Based on the hourly Day-Ahead Market (DAM) as the reference price.
- Provides flexibility for generators to sell excess production through PPAs.

Similarities with the Danish CfD

- Both countries employ CfD mechanisms to support wind energy.
- Both have a system of caps to prevent extreme bids and provide market stability.

- Each is designed to attract investment by providing long-term price visibility.

5 CONCLUSION

This master's dissertation examined the mitigation of long-term price risks by renewable energy developers through the adoption of CfDs within the EU WEM. The study underscored the role of CfDs in stabilizing revenue streams, thereby accelerating the deployment of renewable energy infrastructures across Europe, aligning with the European Commission's policy goals. The thesis primarily builds on the scholarly works of Schittekatte and Batlle (2023a), Newbery (2023), and Schlecht et al. (2023).The research gains significance in the wake of the gas price fluctuations resulting from the Ukraine-Russia conflict and the consequent call by Ursula von der Leyen for an EU WEM redesign.

This analysis delved into the inefficiencies of the current EU WEM structure and the traditional CfD contract designs, revealing that competitive auctioning for setting a strike price effectively reduces developers' capital costs. Thus, this is seen as the most effective strike price determinant. Nevertheless, the traditional CfD design introduces a distorted perspective on the intraday market due to an inappropriate choice of reference price period. Employing the day-ahead market's hourly spot price as the reference price results in a 'produce-and-forget' mentality among investors, driving them to prioritize output maximization over least-system cost production, with the added risk of negative pricing.

Efforts to address this by extending the reference price period inadvertently led to another issue: the generated output's undue influence on CfD payouts. The literature review explores various avenues to detach actual output from these payments, proposing a contract design that hedges against both price and volume risks and addresses initial structural distortions. This proposed design features an annual reference price period and a competitive, technology-specific auction that awards contracts via a highest-accepted-bid method.

The financial CfD, as conceptualized by Schlecht et al. (2023), is posited as the optimal approach to mitigate long-term price risk for intermittent renewable electricity, curtailing day-ahead, intraday, locational, and volume risks, irrespective of weather conditions.

This financial CfD model promises the most stable revenue for renewable energy developers at least-system cost, bolstering the rapid deployment of renewables in Europe, consistent with the EU Commission's recent policy proposals.

The dissertation concluded with an analysis of Danish and Spanish wind CfD structures, favoring the Spanish model for its incorporation of some merchant risk exposure within its framework. In contrast, the Danish model's lack of such provisions led investors to seek alternative contractual arrangements. Additionally, the Danish model's use of an annual reference price versus the Spanish model's hourly spot rate is noted, with the former being less distortive.

Lastly, there is a need for further research into CfD designs that balance the level of interventionism with the allowance of merchant risk. This research could be informed by existing work on optimizing the CfD-merchant revenue mix, such as the work of N. Gohdes, P. Simshauser, and C. Wilson. Further, the financial CfD design discussed in this dissertation has not yet been applied in practice, remaining a purely academic concept. Future research should investigate the recommendations proposed by this CfD design and evaluate its short-term and long-term implementation feasibility, considering the high administrative complexity associated with it. Additionally, assessing the effects of the financial CfD implementation across different RES-E technologies is imperative. Lastly to be able to provide an all-encompassing revision of a CfD contract, exploring efficient ways to convey the benefits of cost reductions from the learning spillover of RES developers to consumers, without exposing them to price risk, is highlighted as a research opportunity.

Hereby, the implementation of CfDs underscores the complexities of energy policy, the balancing between influencing incentives and carrying out market forces, and the evolving nature of the EU measures to obtain a greener energy landscape.

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APPENDICES

Appendix A – *Dataset of hourly day-ahead spot prices of the German-Luxemburgish bidding zone for the year 2023 retrieved from the ENTSO-E Transparancy Platform*