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Financial Wind CfDs

The problems of contracts for differences and how
forward contracts can help solve them

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Abstract – Contracts for differences are widely discussed as a cornerstone of Europe’s future electricity market design. In this paper, we make three contributions to the debate. First, we summarize the dispatch and investment distortions that traditional CfDs cause. Second, we propose an alternative CfD specification that we dub “financial wind CfDs”. It is a hybrid between CfDs and forward contracts that aims at being superior to conventional CfDs both in terms of risk mitigation and incentives. Third, we point out that “the other side of the contract”, the government’s financial position resulting from any long-term contract with generators, must be carefully handled to avoid muting consumers’ flexibility incentives or depleting forward markets.

1. Introduction

Contracts-for-differences. In the ongoing debates on reforming the electricity market design in Europe, contracts for differences (CfDs) are in the center of discussions. Many commentators have suggested that CfDs should become a cornerstone of the EU's future electricity market. CfDs are financial contracts that specify payments from a buyer to a seller if the price of an underlying is below the agreed-upon strike price and a reverse payment otherwise. CfDs are financial derivatives used in many asset, security and commodity markets, usually in trades between two commercial entities.

Electricity CfDs. In electricity markets, contracts for difference conventionally have a narrower meaning. Here, they refer to long-term contracts between an electricity generator and a government ("public CfDs") that use the hour-by-hour day-ahead prices as underlying. The hourly payment is calculated as this price difference multiplied with the electricity produced by a specific asset, such as a wind park. This "weighting" of price spreads with fluctuating volumes sets electricity CfDs apart from other CfDs used in financial and commodity markets, but also from electricity future contracts. The goal of CfDs is to increase long-term stability both for producers and for consumers, intermediated by the state. With price risk mitigated, generation investors have lower cost of capital and hence lower levelized energy costs. In Europe the use of CfDs became widespread with the UK electricity market reform of 2014.

Problems. In this paper, we identify some of the problems that arise from CfDs as they are used in electricity markets and discuss remedies. CfDs provide "produce-and-forget" incentives in the sense that they mute electricity price variation: generators have no benefit of producing electricity when its needed most. Also, they distort short-term intraday and balancing markets, and while they mitigate price risks, they do not reduce volume risks. To address some of these problems, first-generation CfDs have been modified, e.g. by introducing a monthly reference period. These tweaks have brought new problems though which triggered additional modifications.

Financial wind CfD. To address these problems more fundamentally, we propose a new type of contract that we dub "financial wind CfD" (it works also for other technologies) that borrows properties from CfDs as currently used by governments and from financial forward and futures contracts that have been used for many years by conventional power generators to hedge their position. The core innovation is to decouple payments from the produced amount of an individual asset. Under the financial wind CfD, the government makes a fixed monthly payment to the wind farm. In turn, the wind farm pays the government the spot market revenue of that month. These revenues aren't, however, the actual revenues of any given asset, but the revenues of a reference wind farm – in other words, benchmark revenues. Relative to traditional CfDs, financial wind CfDs have the benefits of further risk mitigation (and thus reduce risk premia further) and avoiding distortive effects. Compared to futures/forwards, the instrument has the benefits of reducing basis risk through a better profile, avoiding margin calls by using physical assets as collateral, and ensuring better availability of such products by making the government issue them.

The consumer side. In the case of public CfDs or any other long-term contract such as feed-in-tariffs, the state passes on the financial obligation to taxpayers or, usually, electricity consumers: someone has to pay the costs and benefit of the proceeds. We refer to this as the "consumer side" (see Figure 1). The way the financial obligation is passed through will have important consequences for price risk mitigation of consumers, but also incentives for demand-side flexibility and energy savings. In this paper, we focus on the producer side but also present some more preliminary thinking on the consumer side in Section 3.



Figure 1: Two contractual relationships – the producer side and the consumer side.

Scope of this paper. This working paper describes observations and preliminary thoughts. It should not be read as a comprehensive assessment or a policy proposal ready for implementation overnight. It is a paper on instrument design: how should long-term contracts between generators and governments be designed? It does not address the question if governments should engage in long-term contracts in the first place, or if such contracts are better left to private firms and markets. This is a complicated question that involves fundamental trade-offs and this paper should not be read as a recommendation of public long-term contracts. Independent of their design, we believe long-term contracts should be an option, not an obligation. Making long-term public contracts (of any kind) mandatory essentially means banning merchant investments which would have adverse effects on investments and would reduce, rather than foster, renewables deployment. The one exception could be technologies where limited sites imply strong market entry barriers, such as in the case of offshore wind.

2. Producer side

In this section, we study CfDs between generators and the state: objectives, design, problems, and alternatives, and suggest a new instrument – financial wind CfDs.

2.1. Objectives

On the producer side, the reason for the introduction of CfDs is to provide long-term financial stability for the investor. At the same time, optimal CfDs should not distort operation and investment decisions.

Investment stability. Renewable and nuclear investments are capital intensive: They come with high investment costs and low or almost zero variable cost. De-risking such investments leads to lower capital costs and thus makes them cheaper. From a risk perspective a one-off payment in the beginning would be best, while a stable revenue stream for the next 20 years would also come close. The reason why the long-term electricity price development is a difficult risk to take for investors is that long-term electricity prices are driven to a large extent by energy policy decisions, from hydrogen support schemes to technology phaseout incentives.

Efficient incentives. A second set of objectives refers to the incentives for plant dispatch, investment, and maintenance that CfDs provide. The benchmark is for CfDs not to distort such incentives.

- **Optimal utilization (operational stage).** CfDs should incentivize plant owners to utilize their asset efficiently (i.e., system-friendly). The incentive should be to always produce when the price is above, and never when the price is below short-term variable costs. This should not only hold on day-ahead stage, but also intraday. Plant owners should make the efficient choice, driven by price signals, between selling at different markets (day-ahead, intraday, balancing). Also, power plant owners should be incentivized to schedule maintenance of power plants according to price signals, so that they try to avoid maintenance during periods of high prices and schedule them to lower-price periods instead.
- **Optimal design and siting (investment stage).** Investors should be incentivized to design plants so that they optimize the generation profile of the plant, balancing the investment costs of system-friendly design choices with their lifetime benefits. Hourly electricity prices are not only useful to guide the utilization of assets, but also transport a rich set of information about the investments needed from a system perspective.

- **Optimal retrofit and repowering (re-investment stage).** Throughout the lifetime of the asset, plant owners should face the efficient level of retrofit, maintenance investment and repowering incentives. The strengths of such re-investment signals should correspond to longer term price levels, so that the incentive for output-maximizing retrofits is stronger during high-price scarcity times compared to low-price oversupply periods.

Prices guide design. Both renewable and conventional power plants can be designed specifically to meet the power system's needs, i.e. produce high value (evening-peak, winter, etc.) electricity, rather than just maximizing overall production. If the price signal is not muted for investors, they are incentivized to make system optimal choices rather than simply maximizing total output. West-facing solar might yield less output than South-facing but produces at higher-priced evening hours. Wind turbines optimized for a higher full-load hours and a flatter generation profile (i.e. producing at full load already under relatively weak wind conditions) create more valuable electricity (i.e. capture higher market prices), but are more expensive than those purely maximized for output maximization. Nuclear can, with some additional investment, optimize its ramping abilities.

Efficient CfD. An efficient CfD should be a good financial hedge but not muting the price signal in order to preserve optimal utilization and investment incentives. This should not only hold for the initial investment, but also for retrofit, repowering, and maintenance investment decisions.

2.2. The benchmark CfD

Benchmark CfD. There are many ways contracts for differences are specified. We discuss more advanced specifications in Section 2.4 below but first discuss a basic specification. In the simplest case, which we refer to as the “benchmark CfD” and which resembles the contracts introduced in the UK in 2014, it is specified as follows:

- the strike price is fixed,
- the underlying is the hourly day-ahead price,
- the CfD is linked to a specific physical asset,
- volumes are “as produced” in every hour (“injection-based”).

The latter means that the payment obligation is calculated for every hour as “(strike price – day ahead price) x produced volume”. Figure 2 shows the spot price during five hours. The payment in each hour is calculated as the price difference (arrows) multiplied with the production (width of the boxes). While this results in stable prices, revenues remain uncertain because of the fluctuation in production.

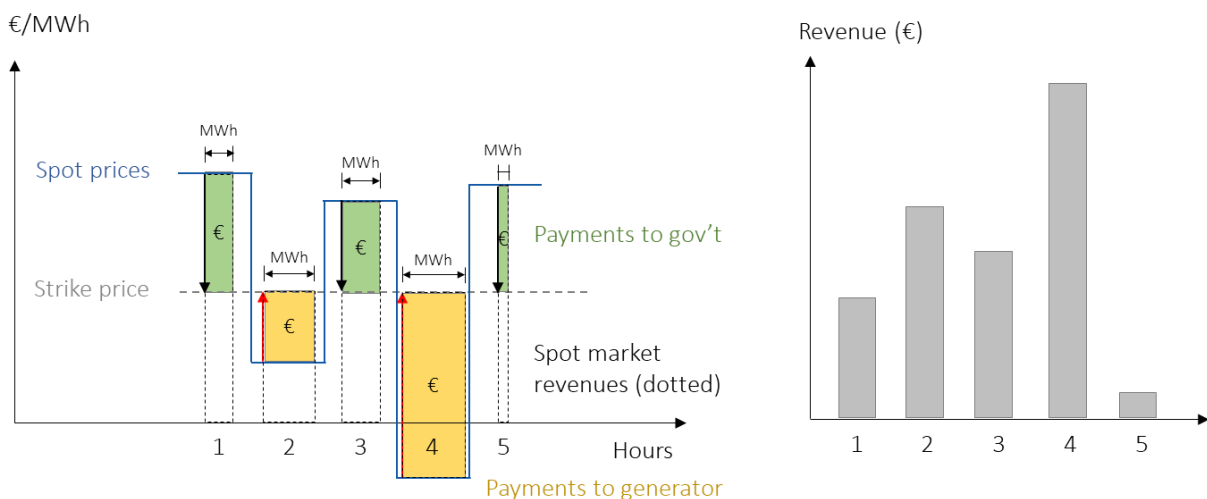


Figure 2: Payments (left) and revenues (right) under the benchmark CfD.

Asset-specificity. While the benchmark CfD is in some ways similar to a financial derivative such as a futures or a forward contract, the fact that it is linked to a specific asset makes it different. Not only does this make it impossible to trade CfDs on secondary markets (without selling the asset, too), but more importantly it entails that CfDs provide incentives to adjust the dispatch of the asset.

2.3. Problems with the benchmark CfD

Three problems. The benchmark CfD design comes with three problems: produce-and-forget incentives, distortion on intraday and balancing markets, and the fact that volume risks remain unhedged. We discuss each in turn.

Produce-and-forget. The benchmark CfD provides a simple incentive to the generator: maximize production. Because the revenues across all hours of production equal the strike price, there is no incentive for the generator to increase output at times of high prices (scarcity), to schedule maintenance at times of low demand, to reduce output at times of low/negative prices (abundance), or to invest in power plants that reap above-average market prices. This has a range of adverse consequences:

- *Investment choices.* When selling to the spot market, wind and solar investors can maximize their revenues by investing into what is sometimes called “system-friendly renewables”: wind turbines with higher towers and larger rotors that produce electricity more continuously; tracking solar panels with higher capacity factors; or west-facing solar that contribute more to high demand during late afternoons. The benchmark CfD provides poor incentives regarding these crucial system-friendliness goals. It results in investment choices in favor of South-facing solar, highly correlated and compressed to few hours wind, and inflexible nuclear.
- *Retrofit and repowering choices.* Investments are not only one-off decisions. Maintenance, retrofit, and repowering investments are decided on during an asset’s lifetime. CfDs often distort such choices, because they mute the price signal, the core scarcity signal of power markets. This means that under CfDs, in an energy crisis, where every kWh matters, too little would be invested into maintenance and retrofitting, and in an electricity glut too much, just to cling on to an old CfD’s subsidy payments. The same applies for repowering of wind turbines, i.e. replacing older, less productive wind turbines with larger, new ones. If an old CfD’s payments are coupled to an old asset, it might not be replaced by a newer, more productive one just to keep the higher CfD payments of the old contract.
- *Maintenance scheduling.* Under the benchmark CfD, generators have no incentive to schedule maintenance at times of low demand. Nuclear power generators may instead schedule maintenance when engineering teams are cheapest (in the winter). Intermittent renewables, where imbalance settlement costs are correlated with spot prices, have an incentive to schedule maintenance in the hours with the highest spot prices to avoid high imbalance costs.
- *Dispatch.* Plants no longer face incentives to increase production in high-price hours or decrease in below-cost or even negative price hours. These issues are problematic for wind & solar (because they should ramp down during negative prices and maximize production at high prices) and nuclear energy (because also nuclear is to some degree flexible), but they are even more damaging for technologies with higher variable costs and/or if these costs change over time. This includes all fossil, hydrogen, reservoir hydroelectricity and storage plants, for which the benchmark CfD is particularly ill-suited. These generators must follow prices, they need to be dispatched according to the demand and supply balance. Providing an incentive to continuously generate electricity would obliterate their economic value as a flexible asset. But these problems also become more severe for wind, solar and nuclear, if larger volumes of the market are covered by CfDs. For illustration, imagine a situation where European heating is electrified, but most generators schedule maintenance during the winter, because they do not care about the high prices during seasons of high demand.

Problematic fixes. Some (but not all) of the “produce-and-forget” issues of the benchmark CfD are fixed in more advanced CfD specifications, in particular monthly reference periods. However, these come with their own problems, as we discuss in Section 2.4.

Intraday / balancing distortion. A second problem is the distortion on intraday and balancing markets. The benchmark CfD uses the hour-by-hour day-ahead price as the underlying. After that auction has cleared, the price of the hourly CfD payment is fixed and known to the generator. From this moment on, it constitutes an opportunity cost and will be priced in, just as any other variable cost component. This has implications for the following market stages, the intraday and balancing markets. If, say, the strike price is 80 €/MWh and the day-ahead price was 200 €/MWh, generators must pay 120 €/MWh for every MWh they produce in that hour. If the intraday or imbalance price drops to 119 €/MWh, it is rational for the generator to curtail output. This implies the loss of low-cost (and often zero or low carbon) production, an upward pressure on intraday prices and potentially more CO₂-intensive production substituting for the reduction of output from low-carbon generators under CfDs. Arbitrage trading implies that such inflated intraday prices spill back to day-ahead and forward prices. The opposite effect occurs in low-price hours, where CfD payments mean payments from the state to the plant owner and generators. In such hours, plant owners subtract the hourly CfD payment from their optimal intraday bids, which means they inefficiently bid into intraday markets below their own variable costs. In both cases, the intraday distortion in combination with day-ahead arbitrage leads to day-ahead prices being more extreme: High prices becoming higher and low prices becoming lower; prices during energy crises being inflated further. To our knowledge, there is no fix to this problem. Calculating CfD payments based on real time imbalance prices is not an option, as it would make generators dump all quantities into the system imbalance, which would compromise system security.

Volume risk unhedged. An additional problem is that CfDs are also imperfect in their goal to hedge revenues for renewable power plants. This is because they leave generators fully exposed to the volume risk (i.e. the wind-availability of the year). To make things worse, they even delete a natural hedge that is otherwise implicit in power markets: When selling to spot markets the negative correlation between prices and wind availability mitigates the volume risk. A low wind year might yield low volumes, but normally is a high-price year. In a CfD context, a low-wind year comes with particularly low revenues, because the lower volume is no longer balanced out by above-average prices. An optimal wind hedge would account for volume risk, too.

2.4. Tweaks of the benchmark CfD

Tweaks. The dispatch and investment incentive problems of CfDs are not new. Therefore, some existing and proposed CfD designs aim at tweaking the contract design so that individual problems are addressed. Often, the tweaks themselves introduce new problems, some of which are fixed in follow-up fixes. Table 1 below outlines various fixes and their problems solved and introduced.

Reference period. Often, CfD designs change the underlying away from the hourly day-ahead spot price towards longer-term averages either of the base price or of technology specific capture prices. This is for example done in the German dynamic market premium (a one-sided downside-cap CfD) or in the Danish hybrid CfD (dubbed hybrid as it combines features of fixed premia with features of a CfD). By calculating the CfD payment based on longer reference periods, intra-period price differences are no longer muted for the generator and create incentives again. Therefore, dispatch and maintenance incentives within these periods are optimized to capture the highest prices again and design choices at investment are done with a view to producing at the highest priced hours within the reference periods. While yearly reference periods also provide seasonal incentives, monthly reference periods do not, as reference periods only provide incentives to optimize production timing within but not across the periods.

Day-ahead distortion as a result. Longer reference periods introduce new problems. The most important new problem introduced is that bids on the day-ahead market are distorted. This is because the CfD payment is already known (or a reasonable estimate can be made) at day-ahead stage, and it is mostly independent of the day-ahead price. Consequently, generators optimize their bidding behavior against the CfD payment. If they know they will have to pay 30 €/MWh due to a CfD in a clawback period, they will no longer produce at spot prices below that threshold. Likewise, if generators know they will get a CfD payment of 30 €/MWh during a support period (i.e., in periods in which the reference price is below the strike price), then they will produce even if spot prices are below variable costs by less than 30 €/MWh, because the CfD payment would compensate operating losses. These incentives are distortive and decrease overall welfare. They also lead to re-arrangements in the merit-order which can result in low-carbon generators not producing (despite prices being above their variable costs) while fossil generators might continue to produce.

Tweaks of the tweaks. To avoid such distortive dispatch incentives, more advanced CfD designs such as the Danish hybrid CfD feature further incentive fixes. For example, no CfD support payments are made at negative prices and CfD clawback is limited to just below the spot price. This ensures incentive compatibility in the day-ahead market. This incentive fix, however, results in stark discontinuities in the resulting merit-order on the intraday market, because whether support payments are made depends on the day-ahead price surpassing the zero threshold, which could cause unintended dispatch consequences on intraday markets. Also, by introducing these incentive compatibility fixes, generators are no longer fully hedged against the price level, and forecasts regarding how often the triggers for the respective incentive fixes will be met have to be made at the investment stage.

Remaining problems. None of the existing tweaks to CfDs addresses all problems of the benchmark CfD. While none of the tweaks addresses the volume risk, they differ in which other risks they address and do not address. Tweaks relating to longer reference periods solve system-friendliness incentives but, for fundamental reasons fail to address the intraday and balancing distortion as well as the inefficient retrofit and repowering choices. Together with the additional revenue uncertainties introduced by the tweaks themselves (see Table 1), these are significant shortcomings remaining.

Capability-based CfDs. A different approach is taken by capability-based CfDs, an approach introduced by Elia Group (2022, unpublished). By decoupling payments from an asset's production (and instead relying on the asset's potential to produce, its capability) it is the only tweak that successfully enables to remove the dispatch inefficiencies with respect to intraday and balancing markets. In decoupling payments from an asset's production, it shares features with the financial wind CfD that we introduce in section 2.6. As the approach, however, continues to rely on an individual asset's production potential, it still mutes the price signal on the investment and re-investment time horizon. Also, relying entirely on the production potential for CfD payment calculation assigns a high commercial relevance to the production potential calculation model, which might be difficult to objectively establish. While such production potential estimates have been used in the past for the calculation of remuneration in case of downward redispatch, relying on them entirely for CfD payments even under normal circumstances significantly increases the stakes and the incentive for manipulation. Unlike the other tweaks, the production potential approach, however, addresses the root of the dispatch distortions, the link between payments and the production of the asset.

Table 1: Tweaks relative to the benchmark CfD, problems addressed, and new problems introduced.

Tweak	Problems addressed	New problems introduced
Monthly reference period	System-friendliness incentives (Only) intra-month maintenance scheduling	Day-ahead-distortion
6-hour rule – No support payments if negative prices prevail for 6 hours or more.	Non-curtailment at negative prices (a consequence of day-ahead-distortion introduced by the monthly reference period)	Bidding uncertainty: negative prices need to be anticipated at the bidding stage already. Revenue uncertainty: Lifetime revenue depend on the prevalence of negative prices.
Danish hybrid CfD – Dynamic premium calculated yearly based on strike price minus last year's base price with two incentive fixes: no support payments at negative prices and clawback limited to just below the spot price.	System-friendliness incentives Suboptimal maintenance scheduling Non-curtailment at negative prices Curtailment at low prices during clawback	Additional revenue uncertainty due to premium being calculated based on last year's prices. A low-price high-wind year after a high-price low-wind year (= large clawback charge) leads to higher clawback than what was earned. Strong discontinuities in intraday merit-order resulting from negative prices incentive fix.
Upper and lower "dead bands" – Different strike prices for support and clawback function of CfDs	(Only) partly addresses system-friendliness and maintenance scheduling incentives.	Makes hedging difficult for plant owners, because the remaining risk cannot easily be packaged into conventional futures products. Financial options are more costly to hedge with.
Capability-based CfDs – Using potential to produce, rather than actual production, to calculate difference payments.	Intraday & balancing distortions	Difficulty of objective production potential data for individual assets, danger of manipulation.

2.5. Forward contracts are asset-independent CfDs

Forward and futures contracts are contracts for differences that have a crucial advantage over other types of CfDs: Asset-independence.

Forwards / futures. One specific type of contracts for differences has been around for nearly as long as liberalized power markets: financial futures and forward contracts. They are contracts for differences

for a specified amount of energy in a specified delivery period. If, as a generator, you engage in a future or forward contract at 50 €/MWh, and the price at delivery is 70 €/MWh, you must pay your counterparty 20 €/MWh, very much like for any other CfD. Futures contracts are traded on organized exchanges, while forward contracts are the over-the-counter equivalent.

Asset-independence. Futures are asset independent, which means that payments are due regardless of any individual asset's production. In other words, they are a financial derivative. Asset-independence has the crucial advantage that – while fulfilling its purpose to provide long-term financial stability for both counterparties (typically producers and consumers of electricity) – they do not distort investment and operation decisions. Under these contracts, generators (and consumers) continue to react to the power market's short-term scarcity as they remain exposed to spot price incentives, while at the same time being financially hedged. This is more important than ever in a system composed of variable renewables which create many new short-term dynamics factoring into price patterns and new types of assets (from battery storages to heat pumps) to both benefit from and mitigate such price volatility.

Shortcomings. Existing futures contracts have three major shortcomings limiting their use as an instrument to provide investment stability for low-carbon technologies.

- **Liquidity and horizon.** They are only available for relatively short time horizons (2-3 years-ahead are liquid, difficult to hedge 10, 20 years ahead).
- **Products and profile.** Existing futures products (such as “base” or “peak” contracts) do not match typical wind/solar generation profiles. Thus, they are a relatively poor hedge for wind and solar generators.
- **Margining.** Futures require large margin payments to be deposited. This is a problem for liquidity-constrained generation firms in offering their production on futures markets especially in periods of volatile market prices.

Addressing the shortcomings of existing futures contracts. Below, we present an idea that addresses these shortcomings. It does so by combining the advantages of asset-independence of futures contracts (and thus avoid distorting dispatch and investment) with the objective of the CfD to be a good financial hedge for wind (or other specific low variable-cost) assets.

2.6. Financial wind CfD

A novel contract. In the following, we present a novel instrument we call “financial wind CfD”. It is meant to be a CfD that (contrary to existing CfD designs) does not distort dispatch, investment, and repowering decisions, but continues to mitigate risk that power plant investors face. This is achieved by creating a financial, rather than an asset-dependent instrument. That means, payments are independent from the asset's production. In addition, we propose to hedge not only price risk, but also volume risk. Essentially, the instrument is designed around two distinct objectives:

- Hedging revenue risk (both price and volume risk)
- Full price structure exposure (for efficient dispatch, investment, and repowering incentives)

The instrument in short. This is achieved by providing a fixed monthly payment from the government to the wind farm. In turn, the wind farm pays the government the spot market revenue of that month. These revenues are not, however, the actual revenues of any given asset, but the revenues of a reference wind farm.

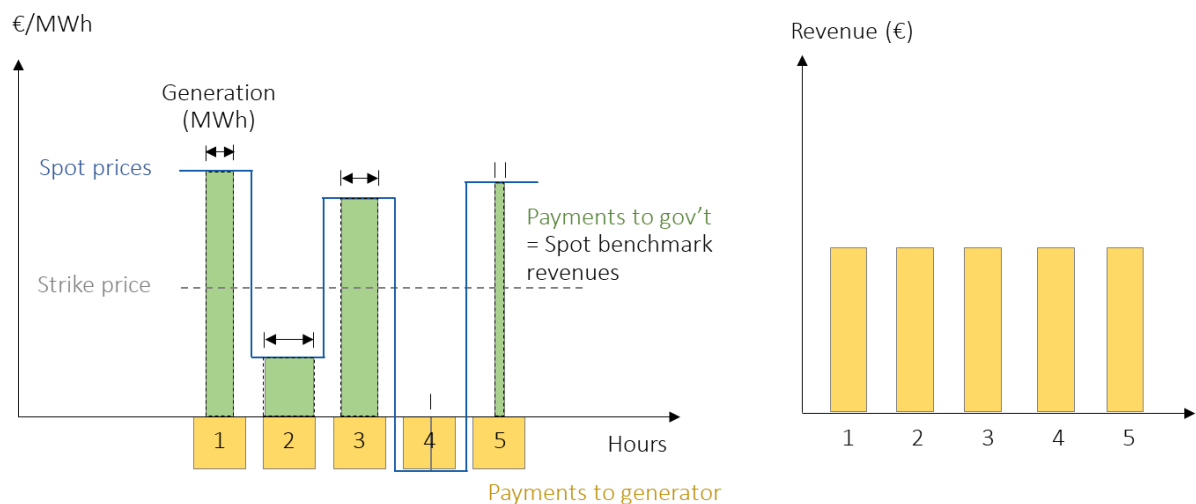


Figure 3: Revenue stream in a wind CfD. Generators get a fixed hourly payment (yellow) but must pay the mathematical product of day-ahead price and wind reference production to the government (green).

Procurement auction. The idea is that the government sets up an auction to procure financial contracts called “financial wind CfDs”. The auction volume, i.e. how many such contracts are procured, can either be set ex-ante, or, better, a demand curve for the auction can be set. A demand curve reduces market power and would lead to the government buying more such contracts if there is plenty of supply at low prices and less if there is only few supply at high prices.

Contract. The “financial wind CfD” we propose specifies 20 years of hour-by-hour payments between the government and a generator. The hourly payment is the difference between:

1. **Payment to generator:** The government pays a fixed, inflation-indexed, hourly remuneration to the counterparty, independent of actual production in these hours. The level of the hourly remuneration is determined competitively in the initial procurement auction.
2. **Payment to the government:** The generator pays the hourly revenues of a reference turbine to the government. The revenues of a reference turbine are defined as the day-ahead spot price (or zero, if negative) multiplied with the hourly output of a reference turbine. The reference turbine is discussed in more detail below. Importantly, it is *not* the hourly output of the specific asset (i.e., the CfD is not “as produced”).

Contract size. The contract size is standardized for a 1 MW reference turbine. Generators can bid for a multiple or a fraction of the standard contract. The contract is a homogenous product because it does not depend on an individual asset’s production. Generators can freely choose the desired contract size, subject to collateral requirements.

Reference turbine. At least three different approaches to defining the reference turbine (it does not need to be an actual turbine) and its hourly production are possible.

- First, a mathematical model that derives reference turbine output based on measured, regionally aggregated weather data could be used. Certainly, averaging a larger region’s weather means it will not be a perfect hedge for any specific turbine, but could be a good enough hedge for many plants. Using weather data as a basis has the advantage of being independent from any individual power plant’s (possibly strategic) utilization decisions but given that large money flows would depend on weather measurement then, it also poses a risk if weather measurement techniques change over time or if strategic actors try influencing weather models.

- Second, a sample of real existing wind power plants could be used. However, there could be strong incentives to manipulate the dispatch of these reference plants, especially if the sample is small. Thus, this does not seem to be a viable approach.
- A third possibility would be to use the output of all wind power plants in a country or bidding zone as a reference. This would be comparable to the German concept of market value (technology specific) used in existing support schemes, although it would need to be defined on capacity basis (EUR of revenue per MW) rather than energy basis (EUR/MWh). An advantage is that given the large amount of wind turbines existing, the potential for manipulation is low. At the same time, potentially distortive incentives stemming from historic support policies would factor into this aggregate reference turbine's output.

Independence of reference turbine. The crucial idea is that the reference turbine should provide a benchmark for production and revenues that is independent of the individual asset's production. This is to avoid the distortive effects known from other CfDs. At the same time, it should be highly correlated to the individual asset, so it serves as a good underlying for a financial hedge.

Net payments. As a result of the difference payment specified above, in high-price and/or high-wind months there will be a net payment from the generator to the government and the opposite in low-price and/or low-wind months. By being a hedge for both the price and weather risk, the instrument helps to stabilize the generator's total revenue. The closer the individual asset's own production is to the reference turbine, the better the hedge.

Collateral. The government should require collateral to back up the financial wind CfD contracts. The collateral requirement would be the only relation between the financial contract and a physical asset. As collateral, the government could accept a newly built wind power plant of adequate size. Accepting financial collateral could also be considered. A possibility would be to introduce certain de-rating factors, so that e.g. a wind plant can only be counted as collateral for max. 90 percent of expected output. This ensures plant owners have enough cash in case their plant produces less than the reference plant and to pay for imbalance costs even in high price periods, despite imbalance costs being correlated to the spot price. Should the generator wish to dismantle or repower its asset, it should be able to exchange the initial turbine that was put down as collateral for financial collateral or to transfer the contract to a new, repowered asset, while ensuring the new asset is not "overbooked". Regulators should be careful in defining these collateral requirements because collateral requirements could yield incentives (during plant design and specification) to maximize the variables which the collateral requirements ask for. If collateral requirements only regarded nominal capacity and ignored site-specific wind and potential full-load hours, they would incentivize turbine designs that maximize nominal capacity at the expense of lower full-load hours, only to be eligible as collateral for larger contract sizes of the financial wind CfD. Designing financial wind CfDs mainly as a (profit neutral) hedge, not as a support mechanism, reduces such risks, as it reduces the desire to maximize collateral eligibility.

Bidding zone split provisions. Any CfD, including the proposed financial wind CfD, should be explicit about what happens to CfD payments in the case of a bidding zone split. Different options would be conceivable in this regard which each have their pros and cons and should be evaluated carefully.

2.7. Evaluation compared to benchmark CfD

Overall welfare. The main advantage of this kind of hedge compared to traditional CfDs is that it does not distort investment and utilization decisions. Efficient plant investment and operation incentives keep overall system costs low. As all payments from the financial wind CfD are asset-independent, it leaves asset dispatch, investment and repowering undistorted and following price signals. But this is not the only advantage of the proposed instrument. It is also likely to reduce financial risks further both for wind generators as well as for the government, enabling to bring down capital costs further compared to traditional CfDs.

For wind generators. The advantage for wind generators is that this hedge targets the absolute amount of revenues, not the per-MWh revenues, so it takes out the volume risk (the windiness risk). Also, experienced developers know how to optimize their asset's generation profile, maintenance schedule, and plant operation to yield maximum profits. Given the exogenous financial nature of the hedge, any additional benefit from optimizing their asset accrues to them in full, rather than being annulled by traditional CfD difference calculation. Targeting the absolute amount of revenues independent from actual generation also helps to mitigate revenue risk for generators from not being dispatched for the sake of maximizing socio-economic welfare even if they could produce electricity in theory. Negative prices are the most obvious case here where not being dispatched and, hence, not being paid a remuneration, is a significant risk for generators largely beyond their control.

For offshore wind generators. Another scenario are offshore bidding zones currently discussed as a market arrangement for future hybrid offshore assets. While maximizing social welfare, such offshore bidding zones might result in revenue risks for offshore wind farms connected to those hybrid assets. This is because offshore wind farms within an offshore bidding zone, due to their clearly determined impact on load flows, would face significantly higher risks of not being dispatched by flow-based/advanced hybrid market coupling algorithms than wind farms connected to conventional onshore bidding zones. Here, traditional CfDs would not offer any risk mitigation as no payment will result from a traditional CfD when a generator will not be dispatched at all. Instead, the proposed financial CfDs will cover this risk and overcome opposition of wind farms against being connected to hybrid assets.

For the government. It reduces financial exposure to weather conditions. In traditional CfDs, governments lose twice in windy years. This is because windy years are (a) high volume and (b) low-price years, increasing the CfD subsidy payments or reducing the CfD income. In our proposal, they are more balanced. The government's CfD income ("the financial call option payout") is influenced by low prices (due to the windy year depressing prices) and by high volumes, two effects which to some degree balance each other out. The same goes for low-wind years, where a traditional CfD's "winning double" situation for the government is replaced by more balanced CfD income too.

Risk of unavailability now correlated to the electricity price. Given that the proposed financial CfD is a financial product that is not tied to the asset's production, its payment flows do not stop if the asset is unavailable. This is a feature, not a bug. It is important to compare the situation with traditional CfDs. In traditional CfDs, generators face the risk of plant outages, as they lead to a complete stop of revenues. In the proposed financial wind CfDs, that risk remains, but what's new is that the risk is now correlated to the electricity price. In times of low electricity prices, unavailability becomes cheaper now compared to traditional CfD settings and in times of high electricity prices unavailability becomes more expensive. The expected costs for an unavailability ex-ante thus stay the same compared to traditional CfDs. The fact that the unavailability risk is now correlated to power prices is a desired feature. Because it provides the correct incentives to invest into urgent maintenance. When power prices are high, generators should be incentivized to spend as much as possible to get the plant running quickly again, while in lower electricity price times they can take more time and thus spend less in maintenance.

Risk of badly performing wind farm. Lower than expected wind is a risk for any wind investment, even under conventional CfDs. Under financial wind CfDs plants are not forced to contract for 100% of expected output, but they can freely choose to use the instrument to hedge only 80% of expected output if they prefer to be on the safe side. This ensures that they are not "overhedged" through this instrument, leading to high payments in times of high electricity prices. The government's collateral requirement must account for the fact that wind farms could perform worse than expected, so it must define collateral de-rating factors.

Additional basis risk. While the proposed instrument takes away volume risks, it adds a new basis risk. This is because the underlying for the volume of the financial wind CfD is a reference turbine and not the actual asset for which it is used as a hedge. Therefore, payment obligations from the financial wind

CfD can deviate from actual revenues made. The risk is symmetric, which means that it can both lead to lower as well as higher than expected income for the generator, but it is now correlated to electricity price levels, which means that underperforming relative to the reference turbine is particularly expensive during high-price times.

Summary. Overall, the financial wind CfD offers a likely more suited hedge than traditional CfDs because the removed volume risk likely outweighs the additional basis risk, leading to overall lower financing costs for renewables. At the same time, the financial wind CfD removes all distortive dispatch and design incentives of traditional CfDs, because full incentives remain to design and operate plants according to price signals – since payments are completely independent of the asset's production, and independent payment flows do not distort.

2.8. Comparison of different CfD specifications

In Table 2, we compare the financial wind CfD to five other CfD specifications with respect to their producer-side effects. We focus on two categories of aspects: the effects on incentives and the suitability as a hedge.

Specifications. The CfD specifications we compare are (1) the benchmark CfD introduced in Section 2.2, (2) a CfD tweaked for system-friendliness incentives by using a yearly reference period instead of an hourly calculation as explained in Section 2.4, (3) a specification that additionally fixes the day-ahead distortions introduced by the change to a yearly reference period according to the tweak of the tweak explained in section 2.4, (4) the Danish hybrid CfD, a dynamic premium calculated yearly based on strike price minus last year's base price with day-ahead incentive fixes, (5) capability-based CfDs as proposed by Elia Group (unpublished) that remunerate according to a concept called available active power (AAP), relying on synthetic production estimates for a given turbine, and (6) the financial wind CfDs introduced in Section 2.6.

Overview. The comparison in Table 2 shows that all specifications 1 to 4, i.e., all specifications that resemble those that were actually implemented by European countries so far, distort intraday (including balancing) markets. Only the proposal by Elia Group of a capability based CfD (5) and the financial wind CfD specification (6) produce efficient incentives for generators to act on intraday markets. The financial wind CfD specification is the only one to provide efficient incentives for retrofit and repowering investments. All others mute the longer-term price signal and thus distort such decisions. Equally, the financial wind CfD is the only one that hedges volume (weather) risk.

Table 2: Checklist for CfD designs

	(1) Benchmark CfD	(2) Yearly reference period	(3) + suspending distortive payments	(4) Danish hybrid CfD	(5) Capability -based CfD	(6) Financial wind CfD
Incentives for...						
... efficient generation profile (RES) or for flexible operation (nuclear)	No	Yes	Yes	Yes	Yes	Yes
... efficient repowering / retrofit / maintenance investments	No	No	No	No	No	Yes
... efficient power plant maintenance scheduling	No	Mostly yes	Mostly yes	Yes	Unclear	Yes
... stopping to produce at negative day-ahead prices	Yes	No	Yes	Yes	Yes	Yes
... continuing to produce at low prices in clawback times	Yes	No	Yes	Yes	Yes	Yes
... efficient intraday dispatch	No	No	No	No	Yes	Yes
Financial hedge for...						
... price risk	Yes	Yes	Yes	Yes	Yes	Yes
... volume (weather) risk	No	No	No	No	No	Yes

3. Consumer side

3.1. Goals

Cost stability. The CfDs the government concludes with low carbon electricity producers can indirectly also serve to protect consumers from cost shocks resulting from energy crises or RES-poor cold winters. Through payments back to the government in high-price times, they serve as a natural hedge for governments making support payments to consumers in such times.

Flex incentives. At the same time, these payments back to and from consumers should not distort incentives for consumers to behave efficiently and follow price signals from electricity markets, e. g. by shifting demand to low-price hours or reducing demand in high-price periods.

3.2. Thoughts

Introducing CfDs – regardless which type – offloads risks (for good reasons) to the government. This has profound consequences for overall risk allocation in electricity markets and needs to be considered in any CfD market design.

Government takes a long position. If the government issues more and more CfDs, a market develops where much of the price risk is taken on by the government. The unhedged long position that the government effectively takes in a CfD regime has three problematic consequences, volatility in government revenues, a dried-out hedging market and a muted price signal that hampers consumer flexibility (if levies/subsidies are used to collect from/distribute to consumers).

Volatility in government revenues. The government's unhedged long position increases volatility of the government's net revenues from its CfD commitments, which necessitates frequent collection/distribution of funds via (often distortionary) levies or subsidies from consumers.

Hedging market dries out. With more and more of the overall market's price risk accruing to the government, it becomes harder and harder for consumers to find appropriate hedging counterparties, because electricity generators, who are the traditional hedging counterparties, lose their natural hedge under a CfD regime and will be reluctant to take on unhedged speculative short positions on their end. This puts upward pressure on forward prices, to the disadvantage of industrial and residential consumers.

Muted price signal would hamper demand-side flexibility. A naïve response to the dried-out hedging market could be “but in a CfD world, there is no need for consumers to hedge”. Because the government would likely distribute income from CfD (in high price times) or collect revenue to refinance CfDs (in low price times) from consumers, effectively balancing their electricity prices. The problem is that in a RES-dominated electricity system, the demand side must also be incentivized to react to price signals – be it by demand shifting due to daily short-term electricity price patterns, or by energy saving due to scarcity of energy supply. If the government starts subsidizing electricity whenever it gets expensive on the market and starts taxing it if it is cheap, such demand reaction is muted. The lump-sum transfer type of support payments seen during the energy crisis do not work for the longer term, because the “last year's consumption” baseline cannot be used forever without distorting incentives. Other useful baselines for lump-sum taxes/subsidies don't exist, so refinancing is always distortionary. In other words, to combine hedging with short-term incentives, functioning forward markets are crucial.

A potential solution. A potential solution to this problem could be that the government develops its own “hedging strategy”, i.e. sells its “CfD volumes” (i.e. its financial electricity long position stemming from CfDs) not only on the spot market, but instead sells these volumes gradually on forward markets, as

they become more liquid, i.e. 4, 3, 2, 1 years before delivery. Staying fully exposed to spot prices (which governments often do in their CfD exposure) is something private companies would never do, and it dries out forward markets. By becoming active in the mentioned shorter/medium term forward markets, the government (a) reduces its own revenue risk (b) helps consumers hedge their consumption (c) while keeping efficient consumer incentives alive.

Power plant investors prefer longer hedges than consumers. With the outlined solution, the government essentially engages in maturity transformation, i.e. it buys 20 year CfDs and sells shorter-term 4 to 1 year ahead forward hedging products. This can be efficient, because for fundamental reasons, electricity consumers often have a shorter preferred hedging time horizon than electricity generators. An industrial paper producer likes to hedge its upstream electricity costs at the same time when it signs its downstream sales contracts for its paper production. Buying electricity longer term risks being stuck to the contract even when spot electricity prices are falling, and competitors can outcompete its production on the paper market. Only few companies can afford to buy very long-term, such as IT companies. Low carbon power generators on the other hand need long-term stability.

Filling the gap. By taking on the “20-year exposure” while giving back at shorter forward horizons, governments fill the gap, reducing capital costs of low carbon generators. Given energy policy’s responsibility for long-term electricity price levels, it could be argued that the risk is allocated where responsibility lies. But having the government take such large financial positions comes at a risk.

Risk of preferential treatment. The increasing role of governments in taking a long position on electricity markets bears the risk of preferential treatment of certain groups of consumers like large or energy-intensive industries over others, creating a rent-seeking game. Therefore, in the context of European discussions going forward, it is important to shed light on this long position of governments (which is an inevitable result of any larger role of CfDs in energy policy), and transparently discuss ways how to deal with it.

4. Conclusion

Problems with CfDs. Contracts for differences in the form currently used provide problematic incentives. These distortions tend to be more severe if non-zero variable cost technologies are included and/or of larger volumes are covered. The tweaks and fixes introduced to avoid such distortion often bring their own distortions.

The Financial Wind CfD. In this paper, we propose a fundamental solution to these problems by borrowing a key feature from financial forwards/futures contracts: decoupling the contract from the production of a specific asset. Instead, we propose to link it to an objective benchmark that is highly correlated with any wind farm, such as a reference turbine. In addition, we propose to accept physical generation assets as collateral for such contracts in order to avoid margin calls.

Consumption side. In addition, we explain that effectively, governments take long positions when engaging in CfDs and propose they close this position by selling these volumes on financial markets. We hope these thoughts provide helpful input to the European policy discussion on contracts-for-difference and electricity market reform.