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RISKS AND INCENTIVES TRADE-OFF IN CONTRACTS FOR DIFFERENCE DESIGN IN EU POWER MARKETS

Kevin Favre, Fabien Roques, Vincent Rious

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Risks and Incentives Trade-off in Contracts for Difference Design in EU Power Markets

Kevin Favre[1,2,*], Fabien Roques[2], Vincent Rious[3]

Abstract

The electricity market design reform presented in Europe reinforces the role of long-term contracts to ensure revenue stability for private investors and hedge consumers from high electricity prices. Contracts for Differences (CfDs) are long-term contracts signed between a private entity and a public entity on behalf of consumers. CfDs have been historically used to deploy renewables in the power system, but they have shown limitations in terms of incentives. To promote market-based incentives, academics and industry experts have proposed adapted CfD designs based on the disconnection between contractual and generation volumes. In this regard, the paper examines how the volume adjustments to classical CfDs modify incentives and affect the trade-off between incentives and risks for investors. The analysis is realized with a realistic power system modelling of 2030. The paper shows that the split between effective and contractual volume restores market-based incentives in the short and medium term. Furthermore, it shows that incentives come at the cost of a higher exposure to short-term price signals at the expense of a potential higher volatility in revenues. It means that risks are allocated differently between parties. Modelling results highlight a clear trade-off between incentives and risk, depending on the contract investigated and the considered technology. The analysis shows that incentives can be returned in the contract design without significantly increasing producer risks within the limits of the paper. Consequently, depending on the parties'

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1 Université PSL, Université Paris-Dauphine, LEDA, CNRS, IRD, Paris, France
2 Chaire European Electricity Markets, Université PSL, Université Paris-Dauphine, Paris, France
3 Université Paris-Saclay, CentraleSupelec, Industrial Engineering Research Department, Gif-sur-Yvette, France
* Corresponding author: kevin.favre@dauphine.eu

1. INTRODUCTION

1.1. Background and context

In the last years and following the global energy crisis, long-term contracts showed a reinforced interest in Europe. On the consumer side, there is a need to hedge against price fluctuation by mitigating price volatility in coherence with downstream redistribution and tariff approach. On the producer side, massive investments required in the power system necessitate a risk-sharing mechanism and a predictable stream of revenues. European countries are thus discussing a predominant role for long-term contracts in the EU market design.

The significance of long-term contractual frameworks is in enabling the establishment of a predictable revenue source for investors, while exercising cost mitigation for off-takers and final consumers. Numerous mechanisms are identified for achieving these primordial objectives, with particular attention being accorded to Power Purchase Agreements (PPAs) and Contracts for Difference (CfDs). Although both PPAs and CfDs are currently understood as financial contractual instruments[1], their principal distinction primarily relies on the contracting parties involved. Specifically, PPAs involve a private entity, such as a final consumer or a utility, as the counterparty, whereas CfDs typically entail a public entity, usually represented by the State through a dedicated agency as the counterparty that acts on behalf of consumers. A representation of these facets is presented in Figure 1.

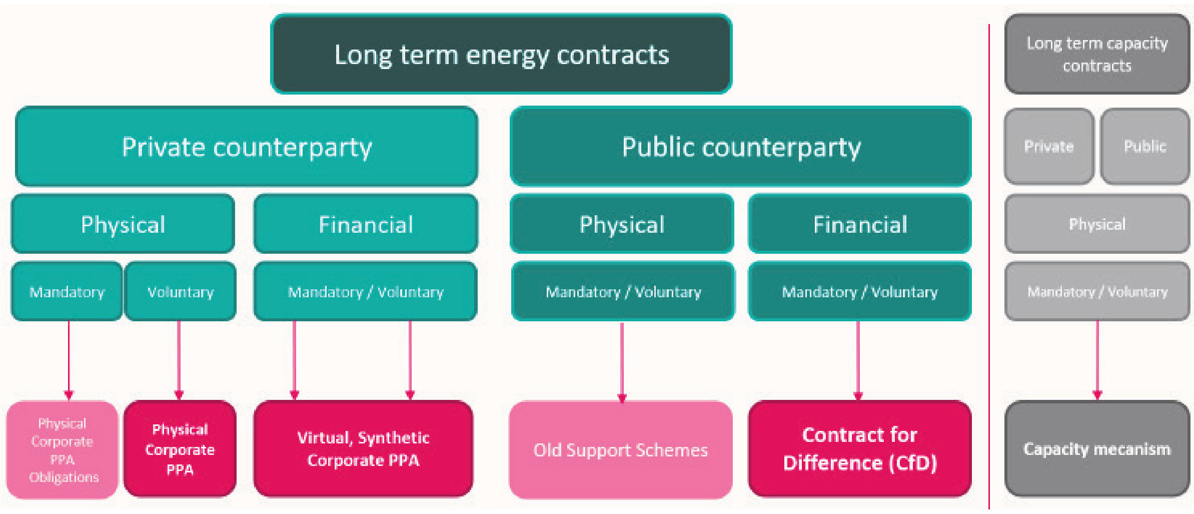

Figure 1 : Long-term contracts typology

For each contract typology, a contractual design is associated based on several clauses (opt-out, duration, payment direction, reference price, clawback at low prices, price indexation etc.). There can be a strong discrepancy in this contractual design, resulting in many possible specifications and possible behaviour incentives in markets.

Focusing on upstream, recent research has investigated the design of CfDs, particularly in terms of potential incentives and distortions. Due to incentives not aligned with power system needs in current CfD, researchers and practitioners thus started to propose non-distortive contracts that are not based

[1] For PPAs, the distinction is more subtle and can either be physical or financial depending on the PPA's typology.

on the effective production of assets when historical contracts were linked to the energy injected. Under such schemes, the remuneration of the asset is not directly determined by the effective production but rather through a proxy (ELIA and ENTSO-E, 2022; ENTSO-E, 2024; Newbery, 2023; Schlecht et al., 2024). However, a contract design disconnecting the remuneration from the effective production implies a modified allocation of risks that is not explored in the literature.

The main contribution of this paper is to analyze the challenges in terms of risk allocation associated with new CfD designs. The paper specifies two new contract designs and analyzes how they can restore market-based incentives. With a realistic simulation model, the paper assesses the impact on risk for investors for different types of technology in 2030. Without pretending to give the right allocation of risks that depend on the public counterparty's risk aversion, it provides insights into the advantages/disadvantages of the different proposed contracts for the technologies investigated in this paper.

1.2. Literature review and research questions

The use of power system modeling to simulate short-term electricity markets and long-term investments is quite common in the literature and relies on different approaches (Cretì and Fontini, 2019; Ventosa et al., 2005). Depending on projected revenues, investment happens if the net present value is positive. In a deterministic world, future revenues are known in advance allowing perfect forecast. In reality, there is uncertainty. Stochastic simulation is a powerful tool to capture it. It includes fluctuations in demand but also in the availability of dispatchable assets, commodity prices or weather conditions. The combination of these aspects leads to revenue distribution and enables the consideration of risks in investors' decisions.

At the same time, prices are becoming more and more volatile with the penetration of non-dispatchable technologies in the power system. Even under the same average price, power prices are subject to more volatility than in the past. Even if part of the fluctuation can be limited with flexible assets such as storage, risk-adverse investors need to hedge against price fluctuation. However, the incompleteness of long-term markets does not provide the optimal risks hedging strategy (Dimanchev et al., 2023; Keppler et al., 2022; Newbery, 2016; Schittekatte and Batlle, 2023). As it is now admitted that agents are risks-adverse (Tietjen et al., 2016), they do not invest at the required level to correspond to an adequate investment level. Due to these limitations, long-term contracts are required to ensure investments to the security of supply criteria level.

In the European Commission electricity market reform, the need for long-term contracts is acknowledged to make investments happen due to limited incentives from the short-run price signal (Fabra, 2023). As final consumers' willingness to pay for long-term hedging is not always aligned with investors one, contracts for difference (CfDs) allow a public entity to represent the interest of final consumers, while providing a lower counterparty risk with a direct impact on financing costs (Gohdes et al., 2022; Neuhoff et al., 2022). CfDs are now used for risk management allowing investors to share risks with a counterparty (Beiter et al., 2023). Indeed, Classic CfD remunerates the power generated and compensates for an agreed price with a market reference price with the aim of removing price risks from investors' hands.

From a modeling perspective some authors show that the hypothesis of the energy-only market does not hold when assumptions are relaxed (Lebeau et al., 2024). In this regard, CfD are a good complement to the energy-only market design, but a right calibration is necessary (de Maere d'Aertrycke et al., 2017). Moreover, long-term contracts show the advantage of mitigating market power and of containing the effects of market abuse (Allaz and Vila, 1993). However, implementing efficient long-term contracts at a large scale in markets requires containing their impact in the short term by limiting (i) market behaviour distortions and (ii) market participation distortions while incentivizing investments in the long term. In the short and medium term, a well-designed contract must ensure that actors are as close as possible to behave as if there were no contracts. In the long term, it must provide incentives for investment in coherence with long-term system needs while assigning risks to parties that deal with it most efficiently.

Although the literature exacerbates that the current design of CfDs is not power system friendly as it induces behaviors unaligned with price signals. To simplify, historic contractual design is based on day-ahead prices and injected generation, or a proxy of it[2]. Due to the contractual design, the incentives of historical CfDs are to maximize the production independently of electricity value, causing distortions in the short-term electricity markets. When the market price is below the marginal cost of production, contract incentives to produce as it is ensured to be paid the agreed price, leading to non-negligeable distortions in markets (ELIA and ENTSO-E, 2022; Höckner et al., 2020; Huntington et al., 2017; Meus et al., 2021). In the same stream, other authors advocate that CfD itself is not distortive, but is rather a contract design framework (Kitzing, 2023).

Initially accepted as a relatively small side effect of these instruments to promote investments, the distortions are already a concern and will be even more in case of large development in the power system. To correct some of these issues, patches were developed in Europe. There are still insufficient, not adapted to all low-carbon technologies, and unsustainable in the long-term.

Modifying the contractual design is a permanent way to avoid distortions without additional corrective measures. One priority in these contracts is to restore (i) the market behavior. Some authors started to propose such alternative designs notably for renewables or storage (Billimoria and Simshauser, 2023; ELIA and ENTSO-E, 2022; Newbery, 2023; Schlecht et al., 2024). In this paper, these modified CfDs are named under the generic term *adapted CfD*. The correction of the distortive aspects relies on the disconnection of the contract's physical volume in favour of an exogenous production. By doing so, the effective production is exposed to the price signal and must respond in coherence with power system needs. While avoiding distortions, these modifications imply a new allocation of risks between the producers and the off-taker.

Author in (Egli, 2020) identifies the main risks for investors in renewables technologies with price, curtailment, resource, policy and technology risks, while in (Petitet, 2016) authors identify volume, price, costs and technical. Moreover, as wind and solar have almost null variable costs, volume risk coming from weather year are smaller than power price risks coming from fossil fuels and are self-hedge concerning volume (Tietjen et al., 2016).[3] In addition, curtailment is not predictable but relies on a volume risk, meaning that curtailment will limit the volume sold in markets. In comparison with (Egli, 2020), it merges curtailments and resource risks under a generic term volume risks. The definitions of risks expressed below are from (Egli, 2020) and are adapted for volume risk.

The impact of the new allocation of risks in adapted CfD design is, to the best of our knowledge, not explored and quantified in the literature. Restoring incentives through the contract design supposes an exposition of the assets (i.e. investors) to market prices for the effective production, leading to higher volatility in revenues.

[2] In practice, some countries use variations of this contract with an average of the previous monthly or yearly spot price for the reference price.

[3] In some aspects, it means that previous CfDs design mainly hedged specificities already self-hedge.

The aim of this paper is to analyze the challenges in terms of risk allocations associated with different designs to provide insights on the advantages/disadvantages of the different approaches proposed for various technologies.

The paper is structured as follows. First, the theoretical framework is presented. It includes in the first part the analysis of historical contract design incentives. The analysis is declined on a selection of contract designs and demonstrates that the modification of the design improves incentives. In the second part, the model is presented. It is used to evaluate the revenues and profits of selected low-carbon assets and to investigate risk allocation. To do so, several uncertainties are used notably on the potential production level of the assets, commodity prices as well as on Monte Carlo weather years. Then, results are discussed by evaluating the performance of each contract and opening the discussion on the impact of design for risk allocation. Finally, the paper concludes and provides policy recommendations with the advantages/disadvantages of the different contract designs proposed for the various technologies.

2. METHODOLOGY AND DATA

2.1. Introduction to CfD Design

CfDs are financial contract hedging price variations. CfDs rely on a difference between a strike price (p_{strike}) with a reference price (p_{ref}) for a contractual volume ($q_{contract}$). CfD financial settlement is expressed in (1).

$$\pi_{CfD} = (p_{strike} - p_{ref}) \times q_{contract} \quad (1)$$

In their application to electricity markets, classic CfD usually uses the day-ahead market as the reference price ($p_{ref} \rightarrow p_{DA}$). Also, it uses the effective production of the asset and the contractual volume ($q_{contract} \rightarrow q_p$). The implementation of these modifications is expressed in (2).

$$\pi_{CfD} = (p_{strike} - p_{DA}) \times q_p \quad (2)$$

As mentioned before, classical CfDs are known for causing market behavior distortions in their short / medium term decisions. Without exposition to market prices actors do not behave in coherence with the fundamental economics (i.e. produce when the market price is above marginal costs and consume when the market price is below the marginal utility).

In consequence, adaptations of the initial contractual design are required. Two parameters of the contract design can be modified: (i) the contractual volume and (ii) the reference price, each correcting either market behavior or market participation.

Modifications of at least one of these parameters change the design of the contract and resulting incentives. In consequence, authors proposed new contractual design mainly by modifying the first parameter, i.e. the contractual volume. The modification of the contractual volume, from an effective production to an exogenous one, ensures a fixed remuneration and removes the opportunity costs creating distortions. Such examples are yardsticks, capability-based or financial wind CfDs (ELIA and ENTSO-E, 2022; Newbery, 2023; Schlecht et al., 2024). In the context of this paper, it is chosen to focus on three designs[4]:

- Classic CfD - distortive: historical contracts considering the contractual volume as the effective production.

- Baseload CfD – non-distortive: contracts using a baseload normative quantity, which is a fixed and flat amount of energy for every hour of a given year that is valued at the baseload price (i.e. as in a forward contract).

- Alpha CfD – partially non-distortive: alpha contracts are partially-backed CfDs. A 75% alpha means that 75% of the effective production is under historical CfD, with 25% fully exposed to market prices.

Classic CfD design is used as a reference contract to illustrate the initial allocation of price and volume risks. The two other contracts are *adapted CfD* that are evaluated in this paper. This paper focuses on the analysis of the main risks which are the price and volume risks. One metric to study the impact of contract design on the allocation of risks is to look at revenues.

[4] The contracts expressed in this paper are inspired by existing contracts.

2.2. Adjsutements and Parameters Modifications

Revenues of a producer under *<u>Classic CfDs</u>*

Total revenues of an asset under a historical CfD are the addition of the market value plus the CfD financial settlement, minus the cost of production c_m multiplied by the quantity produced, as expressed in (3).

$$\pi_{Classic_{CfD}} = p_{DA} \times q_p + (p_{strike} - p_{DA}) \times q_p - c_m \times q_p$$
$$\pi_{Classic_{CfD}} = (p_{strike} - c_m) \times q_p \tag{3}$$

To evaluate the behavior under such a contract, profit maximization is estimated by computing the derivative of the asset revenue with the produced volume (4).

$$\frac{\partial \pi_{CfD}}{\partial q_p} = p_{strike} - c_m \tag{4}$$

In (4) the derivative translates that any additional production of q_p would lead to a revenue p_{strike} minus c_m, independently of the power system price. The asset is incentivized to maximize production at any hour of a given day, dissociated with the spot price. In consequence, the incentives are not consistent with power system needs. Hence, the contract is not replicating a behavior as if there were no contract and is judged distortive. For this reason, that typology of contract cannot be deployed to dispatchable assets. Otherwise, they will be incentivized to maximize production at any hour.

Revenues of a producer under of *<u>Adapted CfDs</u>*

The re-establishment of the market-based incentives lies on disconnecting the remuneration of the CfD from the effective production[5]. *Adapted CfDs* studied in this paper thus propose different solutions to disconnect the CfD from production. In these contracts, the volume exposed to the CfD is not linked to the effective production, rather an exogenous one. For a normative quantity ($q_{contract} \rightarrow q_{norm}$), the expression of revenues is the sum of market and CfD revenues and is expressed in (5).

$$\pi_{asset} = p_{DA} \times q_p + (p_{strike} - p_{DA}) \times q_{norm} - c_m \times q_p \tag{5}$$

With the same reasoning as in (4), the derivative of (5) is estimated for the produced quantity. It provides the solution (6).

$$\frac{\partial \pi_{CfD}}{\partial q_p} = p_{DA} - c_m \tag{6}$$

In equation (5), as every additional megawatt-hour produced is exposed to the market price, the disconnection of the CfD from effective production incentivizes to respect the fundamental economic of the short-term power market, meaning that the decision to produce one more unit of energy is independent of the contract and is only based on market prices.

Starting from this approach (i.e. the imperative to disconnect contractual production from the effective production), the reasoning is deployed for the *Adapted CfDs*, i.e. baseload and alpha, to express how these designs can restore CfD incentives.

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[5] Changing the reference price also provide incentives, but more on market participation (depending on the chosen reference price) rather than market behaviour. This aspect deserves further research that are not in the scope of this paper.

For baseload CfD, the expression of the asset revenue under a Baseload CfD is the combination of several terms. It combines the revenues from the baseload contract, the CfD revenue and the valuation of any production above the baseload normative production at the market price such as expressed in (7).

$$\pi_{asset_{Baseload}} = q_{norm} \times p_{baseload} + q_{norm} \times (p_{strike} - p_{baseload}) + p_{DA} \times (q_{p,h} - q_{norm,h}) - c_m \times q_{p,h} \quad (7)$$

The derivative of Equation (7) by the effective production q_p is estimated to examine the incentives to produce any additional megawatt-hour and is expressed in (8).

$$\frac{\partial \pi_{asset_{Baseload}}}{\partial q_p} = p_{DA} - c_m \quad (8)$$

The profit derivative confirms that the decision is founded on the difference between the market price and the marginal cost of production in coherence with initial short-term market decisions. It corresponds to the results previously expressed and confirms that baseload CfD as designed here are not distortive.

For alpha CfD, the expression of the asset combines the revenues from the market and from the contract, as the CfD partially covers the effective production of the assets as expressed in (9).

$$\pi_{asset_{alpha\ CfD}} = [(p_{strike} - p_{DA}) \times \alpha + p_{DA} - c_m] \times q_p \quad (9)$$

The derivative of Equation (9) by the effective production q_p is estimated to examine the incentives to produce any additional megawatt-hour and is expressed in (10).

$$\frac{\partial \pi_{asset_{alpha\ CfD}}}{\partial q_p} = p_{strike} \times \alpha + p_{DA} \times (1 - \alpha) - c_m \quad (10)$$

The resulting equation shows that, as expected, there is still a distortive aspect of the contract due to effective production in the CfD design. This distortive aspect will provoke non-compatible market behavior from the asset, notably stopping production at a predetermined price threshold, $p_{DA_{threshold}}$, solving $\frac{\partial \pi_{asset_{alpha\ CfD}}}{\partial q_p} = 0$ as expressed in Equation in (11).

$$p_{DA_{threshold}} = \frac{C_m - p_{strike} \times \alpha}{1 - \alpha} \quad (11)$$

This threshold requires specific attention. It indicates the value below which a distortive effect appears, pushing the asset not to produce. Instead of stopping production when below zero, it incentivizes to stop production when market prices are below this value (opportunity costs). The intuition is such that, up to this threshold, the strike compensates for the market price. If this threshold is negative, the asset keeps producing even if the power system does not require it, meaning distortion in the short-term incentives. However, as it is already the case today, contract might be suspended in case of negative prices. The studied alpha CfD design also assumes the contract is suspended when the spot price is negative. In short, for positive market values, the contract applies; for negative market values, the contract does not apply, avoiding distortion. For the selected modelling below, this threshold appears for negative values and can be easily replicated with the data available in Figure 3.

Previous paragraphs showed that the restoration of incentives is possible. It relies on an exposition to market prices, even partial exposure supplemented by contractual mechanisms. However, the restoration of incentives comes at the cost of additional risks. These risks are explored in the next section. For the the next section, all CfDs behave as they were no contracts in the short / medium term.

2.3. CfDs sensibility to price and volume risks

One consequence of the initial contract design was to push market risks towards the public counterparty. By correcting the incentives, the modification of the contract design reallocates risks between the parties. Risks can be of different natures. Following the literature review (Egli, 2020), it is proposed to keep the two following definitions:

- **Price risk:** *The risk of price volatility within a stable policy regime (e.g., merchant price exposure under a feed-in premium policy).*
- **Volume risk:** *The risk of lower revenues due to inaccurate resource potential estimation (e.g., wind speed or solar irradiation) and unexpected curtailment (e.g. grid bottlenecks).*

These risks can be applied to the contracts in the scope of this paper. The estimation here is qualitative and is from the investor's point of view.

	Price	**Volume**
Without CfD	*High*	*High*
Classic	*None*[6]	*High*
Baseload	*Medium*	*High*
Alpha	*Medium*	*Medium*

Table 1 - Estimation of risks supported by investors depending on contract design

As previously mentioned, classic CfD covers the price risk. One way to analytically prove it is with the revenues' derivative by the reference price that is null, see for instance Table 2 below. There is a more subtle conclusion for the baseload contract, where the exposition is the difference between the normative volume and the effective production. In general terms, marginal risk exposure is summarized in the table below.

	Price	**Volume**
Without CfD	q_{prod}	$p_{DA} - c_m$
Classic	0	$p_{strike} - c_m$
Baseload	$q_{prod} - q_{norm}$	$p_{DA} - c_m$
Alpha	$q_{prod} \times (1 - \alpha)$	$p_{strike} \times \alpha + p_{DA} \times (1 - \alpha) - c_m$

Table 2 – Expression of investors' risks exposure depending on contract design

[6] If based on day-ahead value as previously defined. Some CfDs use an average of previous monthly spot prices.

2.4. Estimation of the strike price for each contract

Two main approaches are possible to estimate strike prices that set the revenues of assets for investments in new capacities. First, in some cases, the strike price is predetermined meaning that the capacities economically viable for the agreed price can develop their project. In other cases, the volume is predetermined but not the price and a competitive auction is led to keep only the least costly capacities up to the predetermined volume. Many countries with open markets use these schemes worldwide (Moreno et al., 2010).

For this paper competitive auctions are assumed. As each CfD design has its specificities, the price strike needs to be determined for each contract. The strike price is determined by investors to cover their costs considering the risks of the projects. Investors are considered risk-averse in coherence with the literature on this topic. Condition Value at Risk (CVaR) constitutes a coherent measure of risk and is common in the literature (Abada et al., 2019; Abani, 2019; de Maere d'Aertrycke et al., 2017). However, the literature does not specify the right value of risk aversion. It is considered a 90% value at risks in the estimation of the strike, meaning that the strike does not consider the 10% of years the most favourable in the determination of the strike. Strike price thus ensures cost recovery is coherent with the CVaR. In addition, the strike price is fixed during the asset lifetime.

As it is assumed pure and perfect competition, the strike covers the total annual costs for scenarios in average under the CVaR condition. As a simplification, it is assumed no arbitrage with total exposure to the market, meaning that opportunity cost is not considered and the auction bid is only a reflection from actual costs of the investment, without strategic behavior if markets prices are above revenues estimated under the contract. The hypothesis to represent full costs is to ensure the economic viability of assets for already invested assets and new assets. In the end, there is only one p_{strike} for each technology and contract. Equations expressed in (12, 13, 14) reflect the settlement to express the strike, with y the Monte Carlo year and h the hour inside a Monte Carlo year.

$$p_{strike\ Classsic\ CfD_y} = \frac{Fixed_{costs_y} + \sum_h c_m q_{y,h}}{\sum_h q_{y,h}} \tag{12}$$

$$p_{strike\ Baseload\ CfD_y} = \frac{Fixed_{costs_y} + \sum_h c_m q_{y,h} - \sum_h p_{DA_{y,h}} \left(q_{prod_{y,h}} - q_{norm_{y,h}}\right)}{\sum_{y,h} q_{norm_h}} \tag{13}$$

$$p_{strike\ Alpha\ CfD_y} = \frac{Fixed_{costs_y} + \sum_h c_m q_{y,h} - \sum_h \left[p_{DA_{y,h}} q_{y,h} + \alpha p_{DA_{y,h}} q_{y,h}\right]}{\alpha \sum_{y,h} q_{y,h}} \tag{14}$$

For illustrative purpose, the contracts are applied to four low-carbon technologies at the French perimeter: nuclear, wind onshore, wind offshore and solar. Country and technologies are chosen for their characteristics, to reflect dispatchable and non-dispatchable assets.

To determine the strike corresponding to the assumptions, the full costs of each technology are estimated. For nuclear power plants, public information provided by the *Cour des Comptes* (Court of Auditors) and the French Regulatory Authority (Cour des Comptes, 2021; CRE, 2023). Variable costs are extracted from the IEA (IEA, 2020).

For renewables, the methodology keeps the value of auctions led by the French regulatory authority. As descending auctions are a competitive approach and as the contract covers the expected lifetime, it is assumed that bidders reveal their true costs. Considering the average value of auctions for each year, the full costs of each additional MW/year in the power system is estimated. The complete costs of already existing capacities are estimated with the same methodology. Full annualized costs for both technologies are estimated.

Once the strike is determined and the model calibrated, the revenue for each realized year is estimated. A revenue discrepancy occurs due to changing conditions between the investment and the scenario realization, corresponding to the risks. Hence, the revenue fluctuation for each design of CfD is expressed in (7) as the rate of change between expectation and realization.

$$\varepsilon_{fluctuation} = \frac{\pi_{realized} - \pi_{expected}}{\pi_{expected}} \quad (15)$$

2.5. Model description

The French TSO, RTE, has developed an open source unit commitment modelling tool named Antares to quantify the economic performance, the security of supply and the environmental impact of power systems ("Antares Simulator presentation leaflet," 2018; Doquet et al., 2008). It lies on economic fundamentals by modelling markets demand and supply to minimize the system operation costs. The objective function of the model is presented in (RTE, 2007).

The tool is robust and regularly used in European projects, national assessments (see for instance (ELIA, 2021a, 2021b; ENTSO-E, 2018; RTE, 2022, 2021a, 2021b)) or in peer review studies (see for instance (Alimou et al., 2020; Lauvergne et al., 2022; Lynch et al., 2022)).

The CfDs impact on revenues distribution are evaluated on a pan-European modelling of the power system in the year 2030. The purpose of the modelling is to investigate the impact of CfD design on revenue distribution.

The model includes each European country as a network node. Each node includes clusters per technology. Interconnections are represented with flow-based modelling. A stochastic approach has been added to capture uncertainty in revenues due to external factors (demand, availability, weather, etc.). Monte-Carlo simulation is a powerful tool in this regard.

The model enables the building of Monte-Carlo simulations by stochastically selecting time-series calibrated upstream. The construction of Monte Carlo scenarios with the hourly time series includes series on the demand, wind and solar generation and hydraulic inflows. They are based on 200 weather-years from Météo France, France's official meteorological and climatological service. In addition, 60-time series are used for the thermal fleet availability based on the statistical distribution of historical availability for fossil and nuclear thermal assets. Weather-years will impact the production profile and annual volume for renewables assets, and the demand depending on meteorological conditions. The construction of the Monte-Carlo simulation in Antares builds the scenarios as presented in Figure 2.

The model is also parametrized to capture uncertainty on commodity prices with three possible gas prices. Details on the inputs are available in Annex 1.

Once physical dispatch is realized, the volume produced for each year is known ($q_{y,h}$) and strike price can be estimated. As contract design will impact how costs are recovered, the strike price level must be adapted to each contract's specificities. The resulting strike prices are presented in Figure 3.

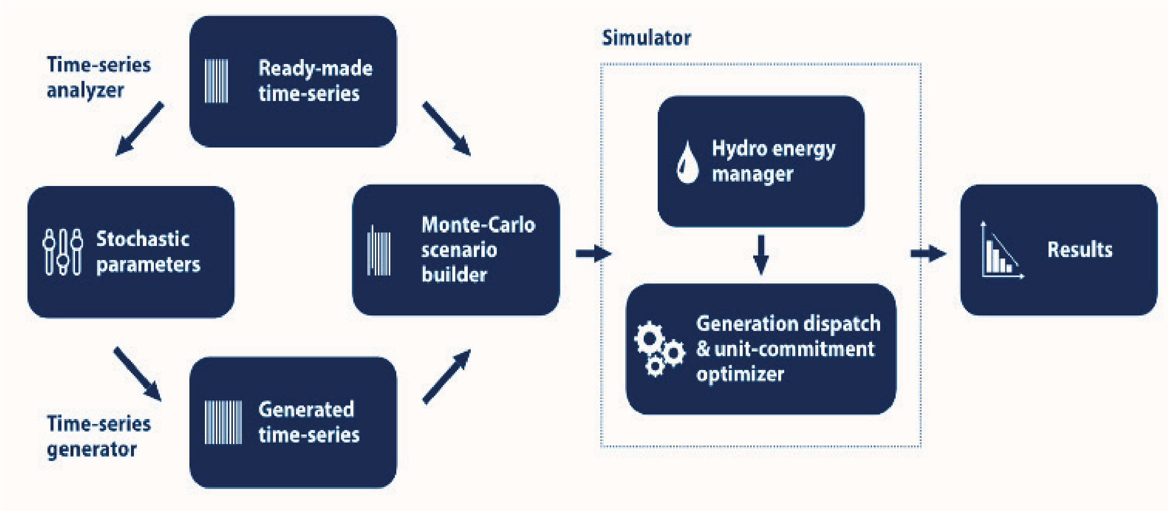

Figure 2 : Functionalities covered by Antares-Simulator.

Contract typology / France	Technology	p_{strike} (€/MWh)
Classic CfD	*Nuclear*	57.0
	Wind Onshore	69.6
	Wind Offshore	102.9
	Solar	133.4
Baseload CfD	*Nuclear*	51.9
	Wind Onshore	79.2
	Wind Offshore	111.4
	Solar	160.4
Alpha CfD (α = 0.75)	*Nuclear*	52.9
	Wind Onshore	73.4
	Wind Offshore	117.4
	Solar	163.8

Figure 3 : Expected strike price for each contract typology under full costs assumptions

Interesting points must be made about the value of strikes and how they vary from contract to contract. Due to the new exposition to market prices, contract design impacts the strike price level due to the price exposure.

Under classic CfD, only the effective volume impacts the value of the strike (see for instance Equation (12) without price risk) and market prices do not impact the results. As a result, the profile of the asset is not valued. However, baseload CfDs consider the value of the electricity produced for the power system, meaning that any deviation from the exogenous contract profile is compensated at the market price. The greater the increase in the strike price between classic CfDs and baseload CfDs, the lesser the profile corresponds to the effective production of the asset.

Finally, alpha CfD is led by market prices, meaning that the production profile is valued at the market price up to the one minus alpha chunk, while the alpha share is secured at a predetermined price, i.e. here, the strike price. Under such an approach, technologies requiring higher revenues than the market prices see their strike price increase to compensate for missing revenues in energy markets. This approach of strike prices ensures that assets are covering their costs on average in all scenarios. However, the question is to evaluate how the assets behave under risks and how revenues can deviate from this certain view.

3. Results and Discussions

3.1. Performance comparison of different CfD adjustments

The results presented here focus on France. Some insights are given in the Annex for Germany. The annex also provides descriptive statistics.

Under full market exposure

Firstly, revenue fluctuation is investigated under a full market exposure, meaning without hedging with CfDs. The total market revenue is computed, and operating costs are withdrawn to obtain net profits. With the reasoning developed in Equation (15), the profits for Monte-Carlo years and commodity prices are aggregated in Figure 5, representing fluctuation in revenues normalized by the total costs. Direct market prices are exposed in Figure 4.

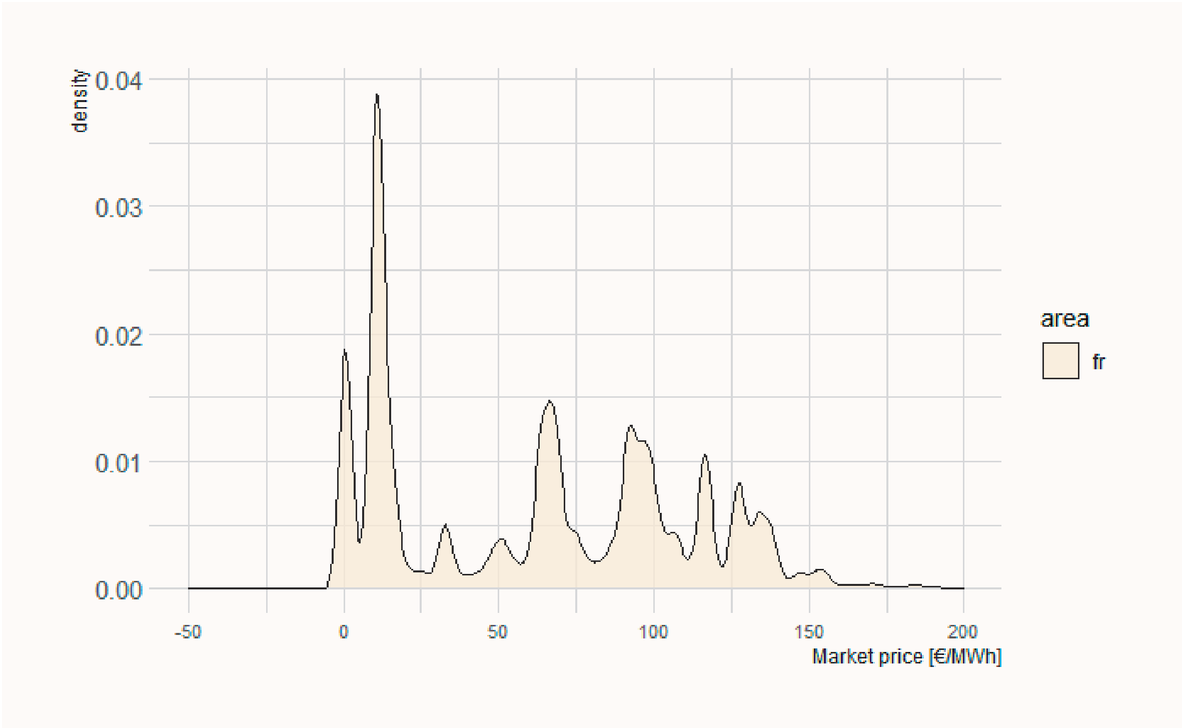

Figure 4 : Simulated price distribution in 2030, France

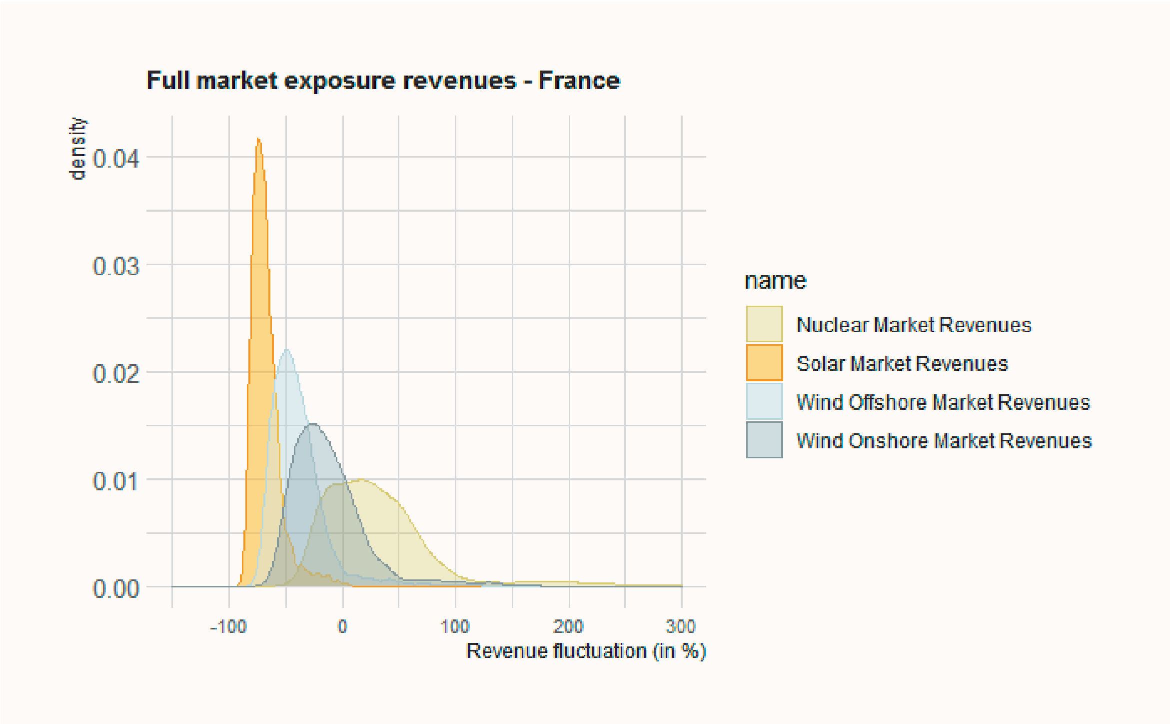

Figure 5 : Technologies profit fluctuation under a full market exposure in 2030, France

The effect of commodity prices impacts the distribution of revenues. In the present case with a complete market exposure, an investor cannot fully ensure a remuneration covering costs equally depending on technologies[7]. In average and without contracts, nuclear earnings are 33.3% above full costs. On average and without contracts, solar loses (-)67.5% of its full costs, offshore wind (-)39.5%, and onshore wind (-)12.6%.

With a broader look at the dispersion inside scenarios, it must be noted that revenue fluctuations are highly spread out depending on the characteristics of the technology and its exposure to price peaks, i.e. the hour of the day with the highest prices. For technologies producing when it has value for the power system, the exposure to market prices leads to a higher spread in the distribution. Nuclear has a wider spread of revenues due to its greater exposure to periods of high prices. Onshore wind has the second most important spread before offshore wind and solar, ranging from -25% to approximately 100%. This spread leads to high uncertainty for investors but also potential high profits at the expense of consumers.

Under long-term contracts (CfDs)

To limit the uncertainty and the spread of the revenues, previously defined contracts are applied to the technologies in this paper's scope. Total revenues combine market revenues and financial hedging, i.e. the CfD. As the strike is determined on average with a risk aversion in the overall weather years as expressed in Equations (12), (13) and (14), it thus differs from the ones realized in scenarios reflecting uncertainty. As for Figure 5, the Figures 6, 7 and 8 present the fluctuation between the effective and expected profit per technology.[8]

[7] The insufficient remuneration is expressed with a revenue fluctuation below zero.

[8] *Main results, notably concerning the statistical distribution of revenues (e.g. mean, quantile, kurtosis, etc.) are available in Annex.*

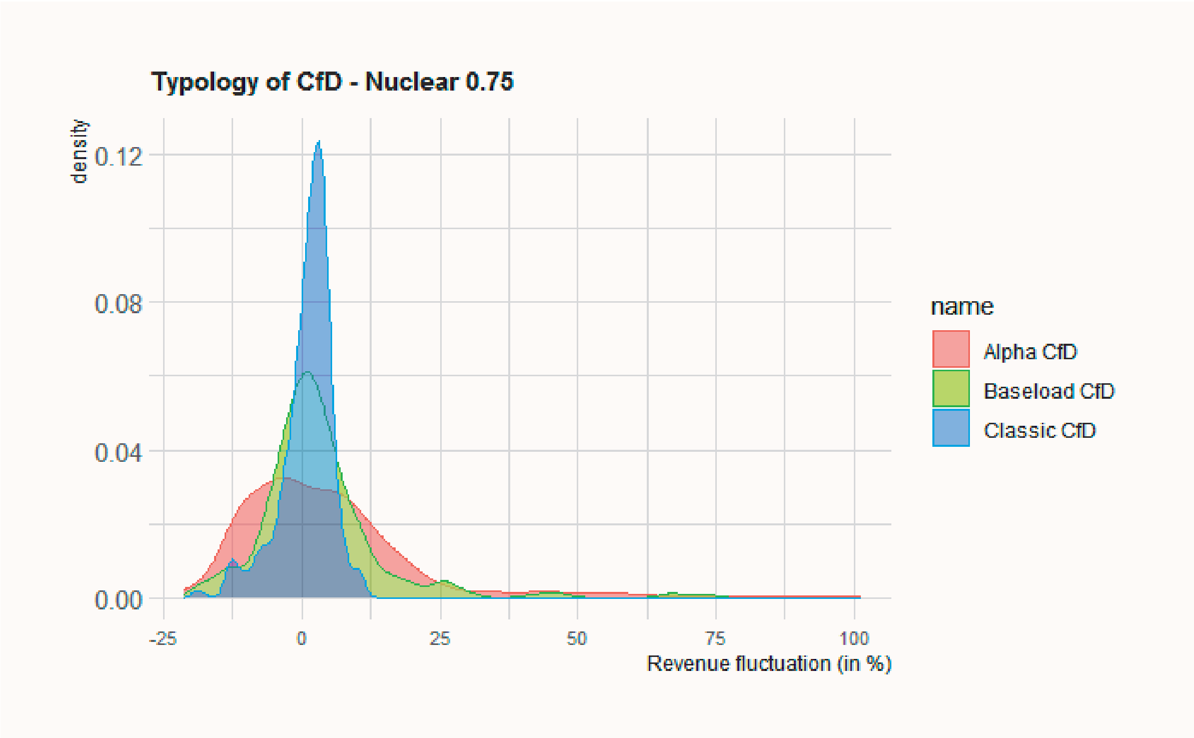

Figure 6 : Nuclear revenue fluctuation for the different typologies of CfDs

For all technologies, the hedge strongly limits the fluctuation in revenues. As a reminder, Classic CfD only exposes the technologies to volume risk without price risks. As the contract fully covers the market price and removes price risk, the only residual risk is on the volume side. The contract design thus concentrates revenues and strongly limits the spread compared to the situation without contracts, limiting the effect of commodity prices. However, as shown in Figure 6, exogenous shocks on production are reflected in the revenue fluctuation due to the exposition to the volume risk. Consequently, revenue fluctuation is contained between (-)20% and 40% under the hedge.

For nuclear, as a dispatchable asset, the behavior of revenues under the contract differs in comparison with other technologies. Alpha CfD keeps part of the volatility on revenues while being significantly less volatile than a full market exposure. As the contract does not fully cover price exposure, the revenues are linked to the original shape (i.e. without contract) due to commodity price scenarios. However, compared with the situation in Figure 5 (i.e. without contract), CfDs limit the spread of revenues, leaving fewer risks to the investors. However, nuclear can capture high revenues when the power system is under stress. Baseload CfD has a slightly similar behavior. As a reminder, normative volume is paid at a fixed price (meaning fixed revenues) while residual production, whether positive or negative, is valued at the market price. Production profile is hence an important parameter. In consequence revenues are a combination of price and volume risks. However, as nuclear is dispatchable, production happens when it has the most value for the power system. It thus earns more than the average in situations of strong tensions on the power system (e.g. when the price is set by peak power plants or price cap). It explains the positive skewness for the portion in high revenues while still having negative fluctuation impacted by the stress scenarios.

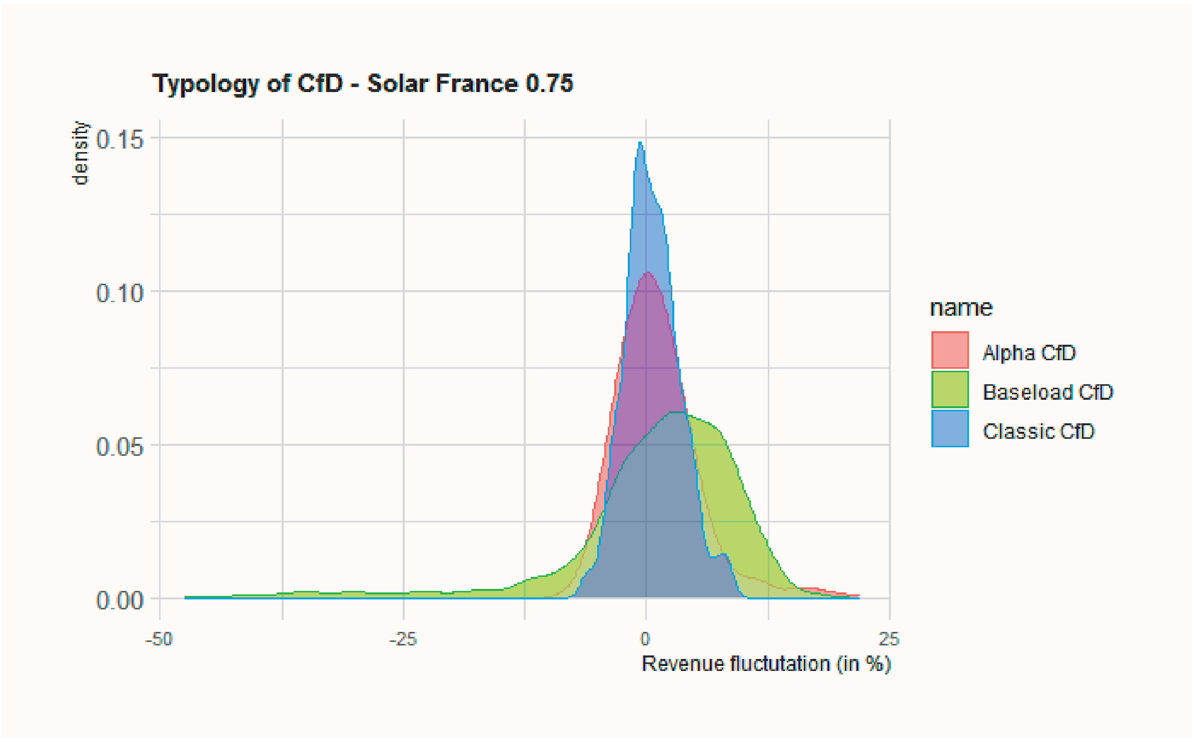

Figure 7 : Solar revenue fluctuation for different typologies of CfDs

For solar and wind, as non-dispatchable assets, they cannot fully determine their moment of production and rely on external factors (when the wind blows and the sun shines). If correlated to the moment of high demand for the power system, they are dependent on commodity prices for their revenues despite not being thermal assets. As alpha CfD secured a share of the price, the distribution is smoothened, limiting the impact of gas prices up to the point where almost no distinction can be perceived in the distribution from scenario prices. Baseload CfD exergues the existence of negative skewness. As the assets are not dispatchable, any deviation from the profile due to weather conditions (e.g. the sun doesn’t shine when expected) leads to being penalized at high market prices linked to market and volume risks.

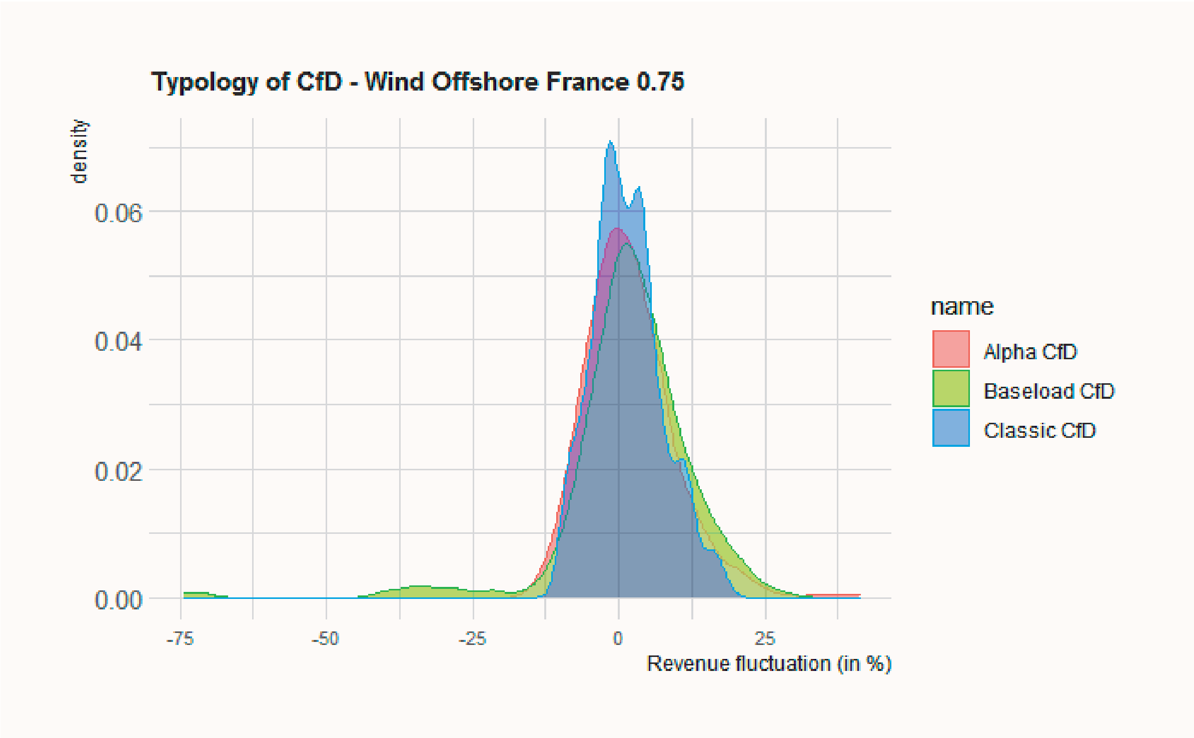

Figure 8 : Offshore wind revenue fluctuation for different typologies of CfDs

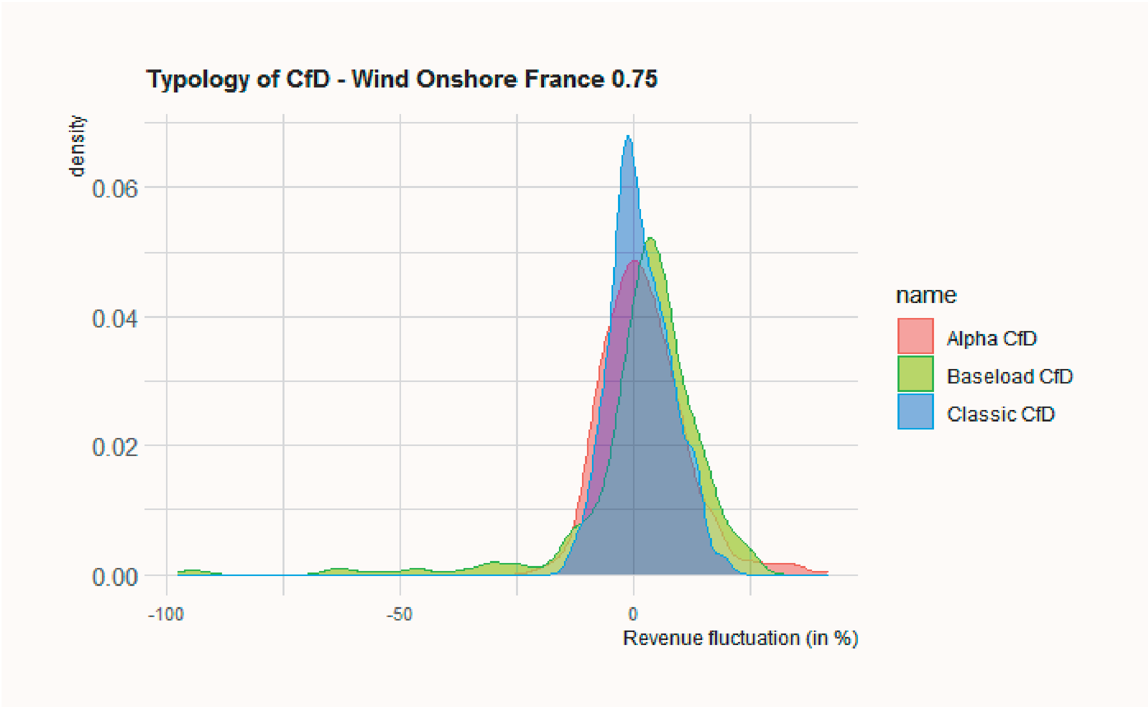

Figure 9 : Onshore wind revenue fluctuation for different typologies of CfDs

Sensitivity to the alpha parameter applied to dispatchable assets

Previous results showed that alpha CfD restores exposure to market prices while keeping the original shape of revenue distribution. However, depending on the value of alpha, the shape relies on the residual exposition to market prices. One remaining question concerns the impact of the alpha calibration on investors' risk exposure. The greater the market exposure for investors is (i.e. the lower the alpha is), the greater the impact of prices on total revenues is, and the lower the risk borne by the public counterparty is. As shown in the previous Figures, this aspect is particularly pronounced for nuclear as it is dispatchable and produces when it has high value for the power system, reflected through revenues driven by commodity prices. Hence Figures 10 and 11 decomposed the impact of the alpha parameter on revenue distribution. The strike price is re-estimated for several alpha values while measuring risk aversion with CVaR. Then, the distribution of revenues is recalculated considering the new design of the contract with the associated exposition.

Figures 10 and 11 show that the lower the alpha is (i.e. the higher the market exposition is), the stronger the fluctuations are. In this specific situation, the analysis shows a pivot point smoothing the effect of market prices. A proxy to capture this switch is to look at the probability of revenues in the 10% worth cases. With this indicator, it is possible to capture how much the contracts cap the worst-case scenarios. The results are represented in Figure 12. It shows that the results are nonlinear, with a turning point around an alpha of 0.9. Moreover, it seems that exposure to market prices leaves, in some specific cases, equivalent risks than being completely hedged.

From these insights, one can ask oneself what the right value for alpha is. The hedge relies on the preference of the parties to bear risks and to the specificities of the power system. In practice, it is more of a public policy decision. The question is how much risk the public counterparty wants to bear and leave to the private investors to ensure the right incentives and limit the cost of capital (limiting the risk in investors' hands).

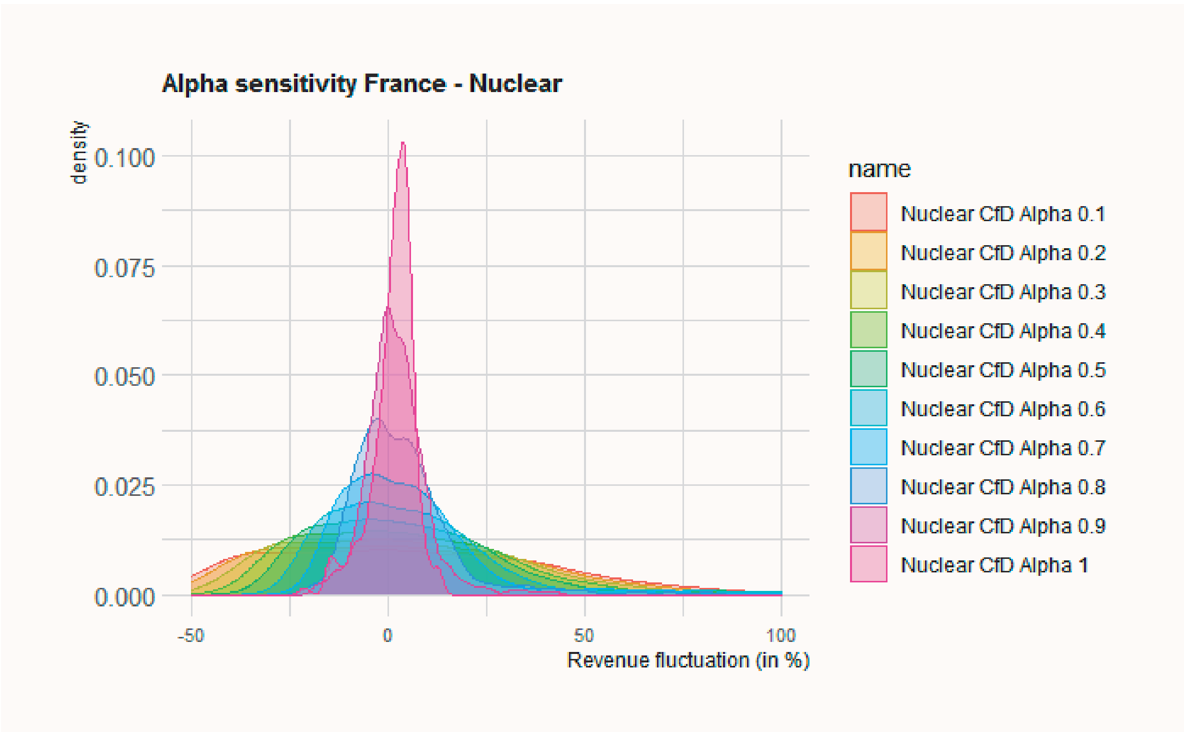

Figure 10 : Nuclear revenues for different alpha in alpha CfD

3.2. Synthesis of main results

Restoring incentives is necessary and means re-exposing investors to price risk. As shown in the first part of this paper, classic CfD design is associated with distortive offers in short markets. At least partially, investors must be exposed to market prices to restore market-based incentives. By doing so, investors are bearing additional risks in their portfolio, and they can handle them or push them toward third parties.

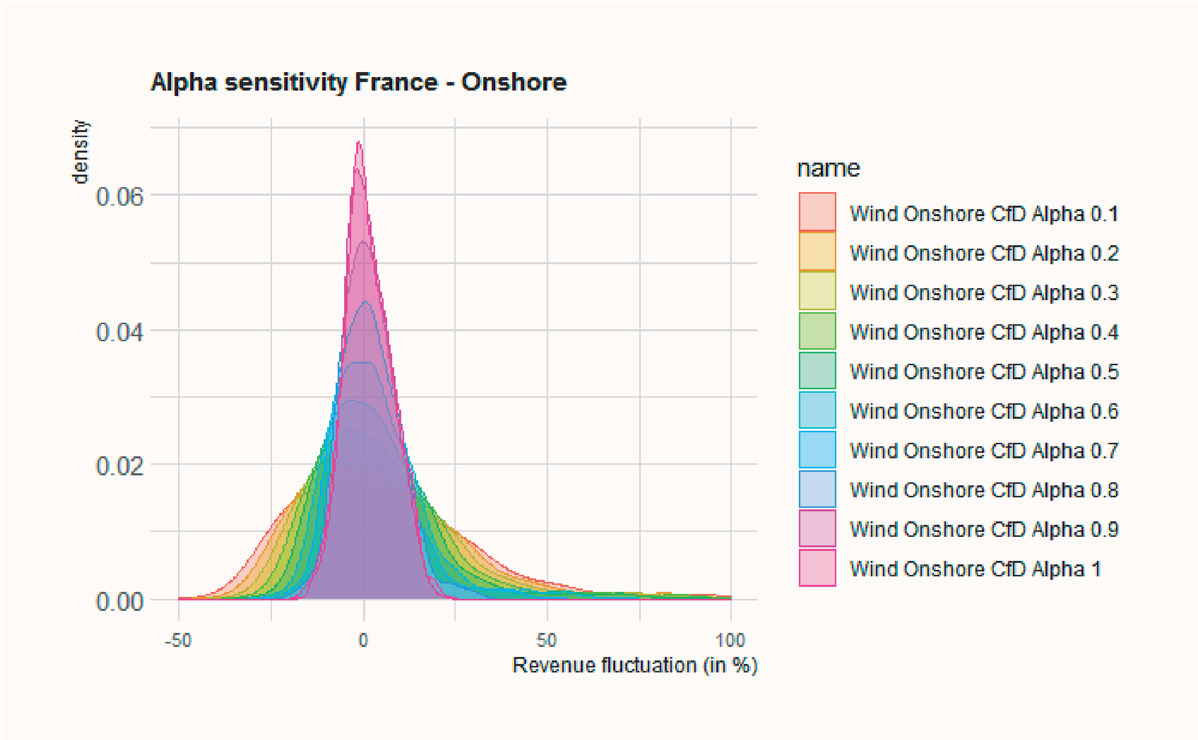

Figure 11 : Wind onshore revenues for different alpha in alpha CfD

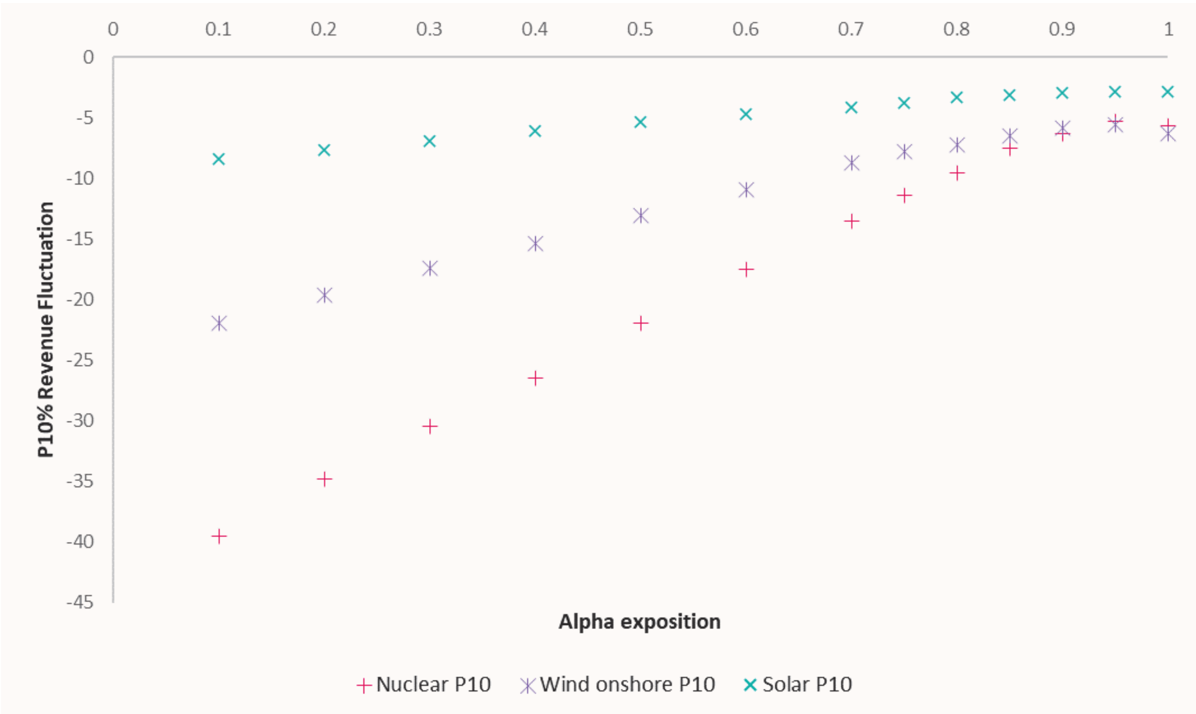

Figure 12 : Sensibility of the 10% probability of revenues to the alpha parameter

A contract design does not impact all technologies in the same way. A contract design must be technology-specific to reflect its exposure to market prices. The impact of the CfDs is not the same depending on the technology specificities and production profile. Even if technologies are non-dispatchable, the impact of the contract can strongly differ depending on the production profile. Contract design will thus give incentives to produce in accordance with power system needs and not only maximize production.

One of the consequences of the previous point is that dispatchable assets are the most sensitive to power price risks. Because dispatchable technologies produce when fossil fuel technologies are marginal, revenues are strongly linked to commodity prices leading to a higher exposure to commodity prices.

The parameter alpha must be meticulously chosen in line with power system specificities and risk preferences. One way to expose to market prices and mitigate power price risks could be to rely on alpha CfD. If well calibrated, it removes the distortive effect while limiting the exposure to market power prices. The lower the alfa is, the higher the exposure to market prices is. If the alpha reaches zero, it is equivalent to a full market exposure. If the alpha goes towards one, it is equivalent to a full hedging. Under such a contract, the level of hedging can be adapted in the contract design to fit policies and the risk level acceptable for the public counterparty.

3.3. Limitations of the work and opening for further research

The work in the scope of this paper can be discussed in several ways. Firstly, the scope of this paper focuses and investigates long-term contracts in the perimeter of CfDs. However, other solutions for long-term contracts exist, notably through private contracts. As discussed here, financial public contracts can be duplicated to financial private contracts. However, it is supposed to relax the hypothesis under the determination of strike prices and assume the potential existence of bargaining, market power and portfolio assets management that are not considered here. This paper believes that both private and public contracts can exist as complementary instruments. The paper does not investigate the proportion of each contract and how risks can be separated between those. The analysis done for CfD also holds for private long-term contracts so that they don't distort the spot market and efficient operation of covered power plants.

Secondly, a question relies on the allocation of risks. One difficulty is to estimate the optimal allocation of risks between the parties. Going towards an optimal allocation of risk would be less expensive than a non-optimal one. However, as markets are incomplete and preferences are not aligned, the public counterparty's role might be to fill the gap.

Thirdly, the absolute value of the strike price in the paper can be discussed. As the paper focuses on quantifying the impact on the allocation of risks, the estimated strike price centres the revenue fluctuation average on zero (up to the CVaR). In reality, the strike price could be computed differently, for instance taking into account that the assets could be fully exposed to the market price after the duration of the CfD, as it is the case in auctions for renewables nowadays (merchant tail). The absolute value of the strike could change, which would impact the average position of the distribution, but not the distribution itself. Hence, the focus should be on the distribution and allocation of contract risks and not on strike values. The belief is that another strike value would not change the outcomes of the analysis; it would only change the centre of the distribution.

Difficulty in hedging against some typology of the contract is not considered. The paper approach considers *the shape* in determining the strike price, and it does not include potential market imperfections that add costs to the hedging strategy. However, despite being important, it does not seem trivial considering such costs.

Concerning the auction processes, it is competitive, meaning that bidders are incentivised to reveal their true costs to win the auction. However, under a regime of high prices, there is the possibility of full market exposure, hoping that the market will provide more than the support mechanism. Consequently, it leads to an arbitrage with the revenues of a full market exposure. This situation happened in Europe during the 2022 crisis, as project developers left support schemes to go full market exposure where revenue expectations were higher. This possibility has not been explored in this paper for two reasons. First, from a full market perspective, it is estimated that the uncertainty is too high in a 20-25 year perspective to go only with the market without any hedging. The cost of capital and debt would be too important to ensure the economic viability of investments. In such cases, the hedge will happen with a private contract, going back to the previous points mentioned in this section. Secondly, it is assumed that a public intervention will encourage investors to go with the public counterparty, as the counterparty will relieve the default risk. These aspects can be discussed and necessitate a stronger analysis.

4. CONCLUSIONS

The electricity market design reform discussion relies on developing and reinforcing long-term contracts. In this framework, long-term contracts derisk investment, facilitating access to capital at the least cost for investors, and hedge final consumers from high electricity prices. However, if poorly designed, it can lead to distortive incentives in the short-term markets. To restore the market-based incentives, Adapted CfDs correct the produce-and-forget distortion by disconnecting contractual production to the effective production. Baseload, Capability-based or Yardstick CfDs are a way to achieve this goal.

Contracts for difference analyzed in this paper have shown that the return of incentives does impact the allocation of risks. When previous papers focused the policy analysis on the disconnection of the contractual volume and the effective production, the present paper provides an analytical approach. It proves that using an exogenous volume as the contractual one avoids any distortive effect in short-term offers. Moreover, the paper extends the contract design by providing quantitative results. It includes two distinctive risks: price and volume.

Covering revenues with a contract for difference strongly limits the revenue dispersion, comforting the effect of the hedge. It increases the economic viability of assets that are uncertain before the hedge.

Assets under contracts do not behave the same way depending on technologies. As expected, Classic CfDs only expose assets to their volume risk. Moreover, Baseload contracts are not suited for non-dispatchable assets due to the production shape. Despite considering the production profile in the strike price calibration, they show a strong asymmetrical behaviour toward negative revenue fluctuations. The emergence of situations of tensions in the power system explains the tail in the distribution. Alpha contracts behave quite well for all assets, as they include self-hedging against price and volume fluctuations. However, such contracts are linked to commodity prices with an exposition that relies on the calibration of the alpha.

The calibration of the alpha by the public counterparty is an important matter. Under the hypothesis of this paper, it is possible to expose assets to market-based incentives with an acceptable risk increase regarding the probability of losses at 10%. Still, under the assumptions taken in this paper, the risks in revenue fluctuation are almost similar to the situation of classic CfD. In this regard, exposing assets to market prices might come at a limited cost for investors while having system-friendly behavior.

Considering these aspects, policymakers might easily restore market-based incentives without relying on estimating an exogenous production. It means an easier way to achieve the same objective.

Precedent lines exposed the impact of the CfD design in a predefined scope. The model only considers a limited range of contracts focusing on one country (analyses for an additional country are available in Annex). It also assumes that the financial cost is unchanged by the CfD design, but it might indeed be impacted.

Further research will need to deepen the analysis with more countries to see the dependency to demand profile and technology mix. Other contract designs can also be evaluated to confirm results (e.g. Load Following contracts or contracts that conjugate other expositions to price and volume). Other low-carbon technologies could also be investigated.

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6. Annex 1 – Model Configuration

The modelling is realized with the availability of the French nuclear fleet, which ranges from 300TWh to 435TWh, with an average production of 390TWh. The distribution is not symmetrical. The uncertainty around the nuclear fleet's structural availability aims to include possible uncertainty in the analysis while also including shocks on production. The structural uncertainty is based on historical data from the unavailability of the EDF nuclear fleet. Moreover, the trajectory of available capacity is based on the announced forecast on the ENTSOE Transparency Platform.

To consider price risks, the evolution of commodity prices must be implemented. As market revenues depend on the power price at the time of production, most asset revenues are linked to commodity prices. Hence, the model represents one central scenario and two sensitivity analyses for gas prices (low and high). In these scenarios, the central scenario is calibrated at 23.8€/MWh, while low and high are respectively at 15€/MWh, and 41.7€/MWh. To follow prices and market tensions prices, CO_2 prices are also adjusted to 90€/tCO_2 for the low gas price scenario, while it remains at 120€/tCO_2 for central and high. Other commodities keep the same values independently of scenarios.

	Gas (€/MWh$_{th}$)	CO_2 (€/t)	Oil ($/b)	Coal ($/t)
Central	*23.8*	*120*	*65.6*	*75.5*
Low	*15*	*90*	*55*	*60*
High	*41.7*	*120*	*115*	*101*

Another important matter for revenues is the production mix. Concerning installed capacities two different approaches are retained for the French and European perimeter. At the French perimeter, the capacity is based on recent national objectives revised in 2022. For neighbours, the capacities are calibrated on the pan-European market modelling database from ENTSO-E, that is directly completed by the different European TSO. For information and reproducibility, values for France and a few selected neighbours are available in Figure 13.

2030		**Countries**		
		France	**Germany**	**UK**
Demand	*TWh*	*627*	*887*	*433*
Renewables				
Solar	*GW*	*45*	*233*	*34*
Wind Onshore	*GW*	*32*	*121*	*29*
Wind Offshore	*GW*	*4*	*34*	*52*
Thermal low carbon				
Nuclear	*GW*	*63*	-	*5.5*
Thermal fossil				
Gas	*GW*	*11*	*41*	*16*
Coal	*GW*	*0*	*0*	*0*

Oil	*GW*	*1*	*1.6*	*0*
Flexibility				
Demand Response	*GW*	*6*	*5.3*	*3.1*
Batteries	*GW*	*0.5*	*36.2*	*17.3*
Import	*GW*	*19.8*	*37.6*	*13*
Export	*GW*	*25.2*	*37*	*13.1*

Figure 13 : Key indicators for France, Germany and the United Kingdom

7. Annex 2 – Complementary Results for Germany

To reinforce the analysis, the same methodology is applied to Germany with the aim of investigating the impact of contracts on revenue distribution. As for France, the full market exposure leads to a more contained dispersion of revenues. However, without a support mechanism and on a full market basis, technologies cannot ensure recovery of its costs on a full market perspective. This effect is more important than in France, with a stronger uncertainty in technologies revenues. It can be added that in the context of Germany, revenues are more sensitive to the commodity prices, reflected through bumps in the distribution.

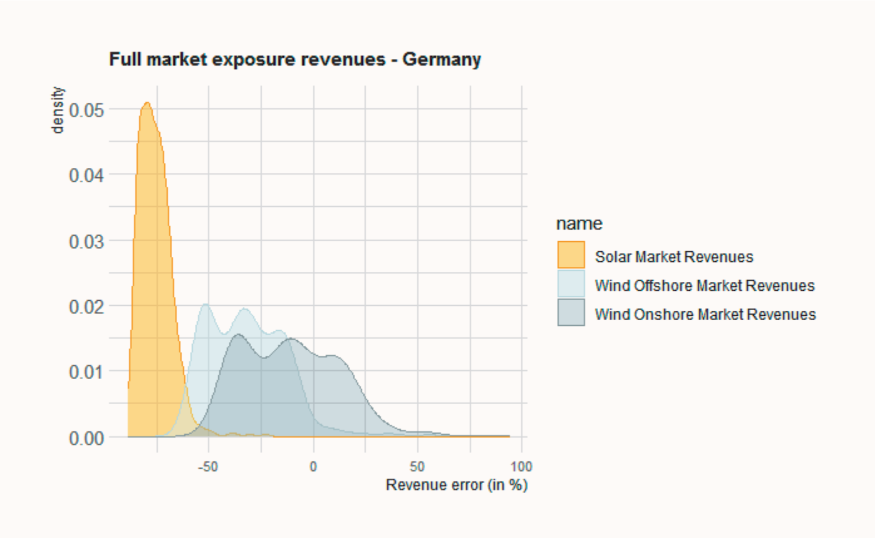

Figure 14 : Technologies revenues fluctuation under a full market exposure in 2030, Germany

In coherence with the proposed methodology, CfD are applied to different CfD typologies. To simplify the analysis for Germany, the full costs for the different technologies are derived proportionally from the one obtained for France. Once again, the main purpose here is not the absolute value of the strike price, but rather the fluctuation around it and investigate if the behavior is the same under another power mix. With the revenues estimated previously, the strike is estimated supposing a competitive auction without arbitrage with going full market exposure. The strike price ensuring the equilibrium between costs and revenues is determined for each technology and each contract, as it was the case for France. Results are exposed in Figure 15 and 16.

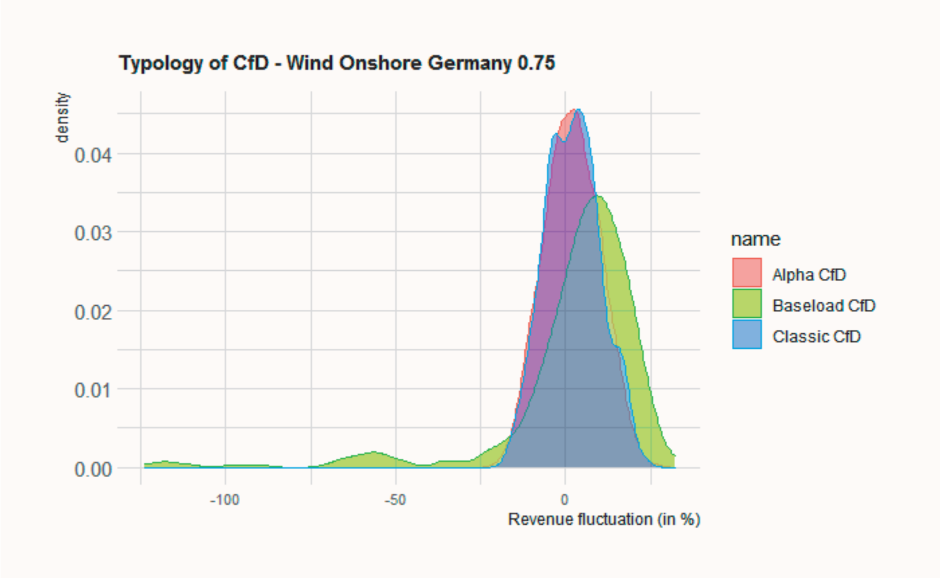

Figure 14 : Onshore wind revenues fluctuation for different typologies of CfDs, Germany

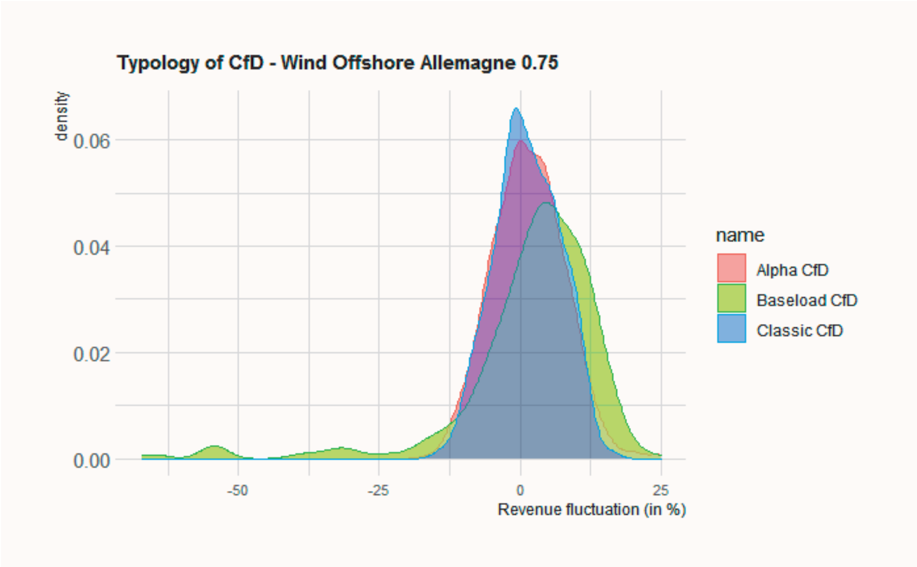

Figure 15 : Offshore wind revenues fluctuation for different typologies of CfDs, Germany

As for France, solar in Germany shows a tail in negative revenue fluctuation under a baseload contract. The Alpha contract restores incentives without being riskier than the Classic CfD on the scope of volume and power market price risks with strong similarities with the classic CfD.

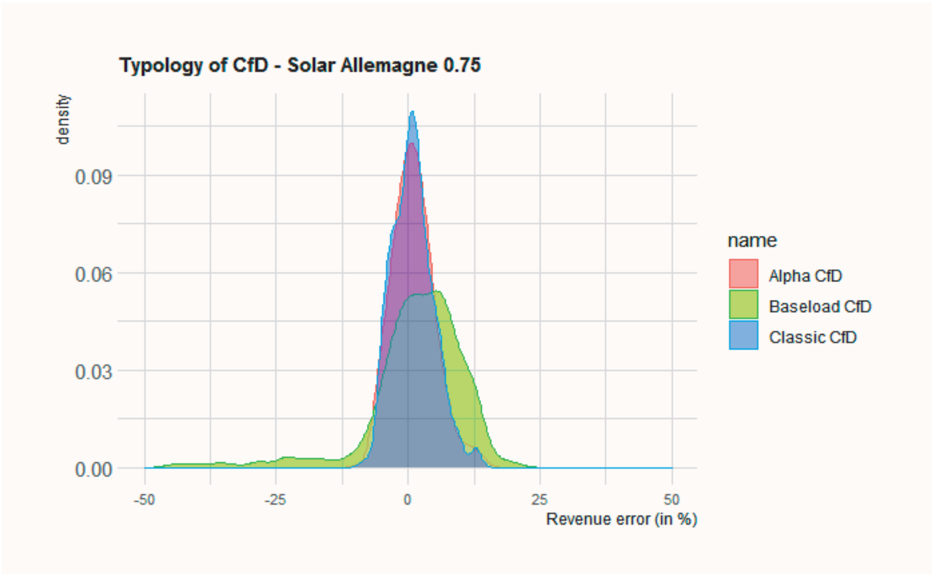

Figure 16 : Solar wind revenues fluctuation for different typologies of CfDs, Germany

8. ANNEX 3 – DESCRIPTIVE STATISTICS

Descriptive statistics, France 2030 – Nuclear

Nuclear	Mean	Std. Dev.	Quantile 5%	Quantile 95%	Kurtosis	Skewness
Alpha CfD	4.26	16.50	-13.10	34.21	11.11	2.28
Baseload CfD	3.05	11.47	-11.84	21.99	14.55	2.52
Classic CfD	0.91	4.67	-8.80	6.75	5.26	-1.21

Descriptive statistics, France 2030 – Solar

Solar	Mean	Std. Dev.	Quantile 5%	Quantile 95%	Kurtosis	Skewness
Alpha CfD	1.07	4.35	-4.84	8.59	5.96	1.22
Baseload CfD	1.19	8.96	-13.5	11.4	9.49	-2.10
Classic CfD	0.65	2.84	-3.78	5.3	3.12	0.35

Descriptive statistics, France 2030 – Wind Onshore

Wind Onshore	Mean	Std. Dev.	Quantile 5%	Quantile 95%	Kurtosis	Skewness
Alpha CfD	2.25	8.91	-9.99	17.6	4.71	0.86
Baseload CfD	2.18	14.2	-17.9	18.5	17.1	-2.93
Classic CfD	1.62	6.44	-8.04	13.1	2.78	0.31

Descriptive statistics, France 2030 – Wind Offshore

Wind Offshore	Mean	Std. Dev.	Quantile 5%	Quantile 95%	Kurtosis	Skewness
Alpha CfD	1.92	7.59	-8.63	15.7	5.18	0.95
Baseload CfD	2.02	10.9	-10.8	17.4	14.8	-2.19
Classic CfD	1.51	5.93	-7.94	12.0	2.90	0.44