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## Contracting matters: Hedging producers and consumers with a renewable energy pool

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Hedging Producers and Consumers  
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Karsten Neuhoff, Fernanda Ballesteros, Mats Kröger and Jörn C. Richstein

Opinions expressed in this paper are those of the author(s) and do not necessarily reflect views of the institute.

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**Contracting matters:**  
**Hedging producers and consumers with a renewable energy pool**

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**Abstract**

Renewable energy installations are rapidly gaining market share due to falling technology costs and supportive policies. Meanwhile, the energy price crisis resulting from the Russian-Ukrainian war has shifted the energy policy debate toward the question of how consumers can benefit more from the low and stable generation costs of renewable electricity. Here we suggest a Renewable Pool (“RE-Pool”) under which the government passes the conditions of Contracts-for-Difference on to consumers who thereby benefit from reliably low-cost electricity supply. We assess the effect on financing costs, scale, and system friendliness of wind investments, as well risk hedging for consumers’ volume risks and hedging incentives.

**Keywords:** Contracts-for-Difference, Renewable Policy, Electricity markets, Financing, PPA

**JEL:** D44 Auctions, D47 Market Design, G32 Financing Policy, L94 Electric Utilities

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## 1. Introduction

How EU energy market design can support the accelerated expansion of renewable energy (from hereon: “RE”) and can contribute to affordable energy costs for consumers is currently being assessed. While short-term electricity markets should provide price signals to market participants (for example by rising prices in times of scarce gas supply),<sup>1</sup> the existing markets have proven insufficient to hedge consumers against such price spikes and to minimize investment risks and financing costs for producers.

This raises the question of how long-term contracting arrangements can be developed to provide the desired hedge for producers and consumers, so as to reduce the level and volatility of consumers’ electricity expenditure, providing an attractive investment framework to realize the renewable deployment targets, while enhancing the effectiveness of the power market in supporting investment and use of clean flexibility options (e.g., demand side response or storage). Two basic options that connect the producer and consumer side are being discussed. First, power purchasing agreements (PPAs) bilaterally agreed between wind- and solar projects on the one side and energy companies or large electricity users on the other side. Second, what we refer to as a “Renewable Energy Pool” (from here on: “RE-Pool”), which connects renewable producers covered by contracts-for-difference to consumers.

The RE-Pool comprises three elements. For producers of renewable energy, it provides long-term contracts to remunerate new wind and solar power projects, so called contracts for differences (from here on: “CfD”) for each installation that is tendered by a government agency. The agency then combines all individual CfD-contracts to a standardized “Renewable Pool” that is allocated to final electricity consumers (industry, private households) on quasi-fixed volume basis (i.e., for a standard weather year). For these consumers, the Renewable Pool provides a hedge against fluctuating power prices for the generation volume according to the generation profile of RE-pool, without diluting energy price signals on short term markets. For governments the pool is budget-neutral, except in situations of contract defaults.

The suggestion of an RE-Pool builds on a number of policy instruments that have emerged in recent years. First, it relates to the design of contracts for differences (e.g., Newbery, 2021, Kröger, Neuhoff and Richstein, 2022, Schlecht, Hirth and Maurer, 2022). With respect to pooling, it relates to suggestion by Grubb, Drummond and Maximov (2022) of a Green Power Pool. It differs however from this suggestion by structuring the hedging payments as a financial hedge rather than as physical delivery. Finally, it relates to the debate about how to allow consumers to benefit from stable generation costs of renewable energy in light of the energy price crisis triggered by the Ukrainian-Russian war (e.g., Fabra, 2022).

We assess, whether an RE-Pool is suitable to address the five objectives of (i) incentivizing RE investment (ii) lowering financing costs; (iii) reducing the volatility of RE supply; (iv) providing incentives for system-friendly installations; and (v) supporting the development of flexibility. These policy objectives have gained political priority against the background of both the ongoing energy crisis and the climate policy objectives, thus highlighting the importance of finding policies that address the needs of the energy system as a whole (Neuhoff, Richstein and Kröger, 2023). With the primary debate at EU level focusing on the difference between achieving these objectives either with a CfD (which can be pooled into the RE-Pool) or Power Purchasing

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<sup>1</sup> If anything, the marginal pricing system in electricity needs to become more fine-grained both in time and in terms of providing locational price signals.

Agreements (PPAs), we compare, where suitable, the RE-Pool against such arrangements, as well as against other renewable policy approaches.

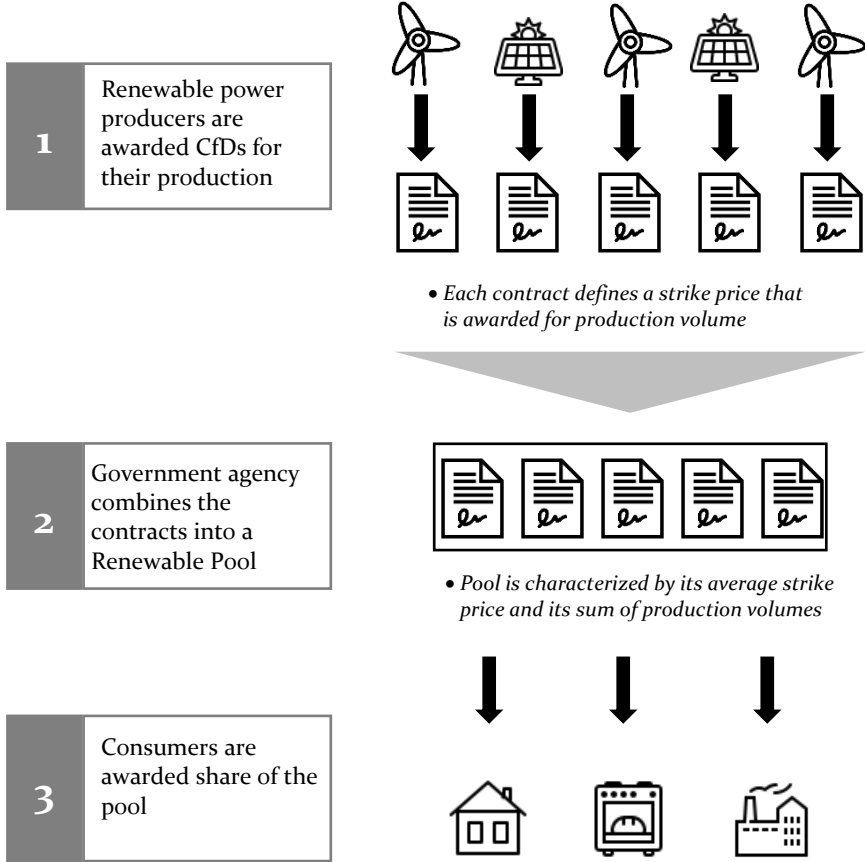


Figure 1 Functioning of the CfD pool

We find that the RE-pool ensures the scalability of renewable installations. In contrast, the capacity of utilities and energy-intensive consumers to underwrite long-term PPAs without endangering their credit ratings is limited. Hence a PPA focused policy design will not be able to back the sufficient renewables expansion. This confirms existing analysis by Baringa (2022), which finds that only 14% of German power demand from industrial and commercial customers can be satisfied by PPAs without affecting the off-takers credit rating. If energy consumers instead access the RE-pool, such limitations do not apply. Furthermore, an RE-Pool has the potential to reduce renewable energy costs by keeping financing costs low compared to PPAs or the historic approach of sliding market premia in some European markets (Neuhoff, May and Richstein, 2022). Additionally, based on recent data, including the energy crisis era, we illustrate that an RE-Pool is effective at considerably reducing energy expenditure volatility and providing green power delivery for off-takers. As the RE-Pool hedge by itself is good but not perfect, it sets incentives to acquire additional flexibility contracts (or realize flexibility potential of off-takers) that complement the renewable profile, thus potentially unlocking flexibility investments. By incorporating a bonus-malus system in the auction design for the renewable CfDs, early incentives can be given for investors to consider system friendliness in their investments.

The remainder of the paper is organized as follows. In the second section, the key design elements of contracts for differences for renewable energy are discussed and their aggregation into a pool is presented. The third section analyses how the “RE-Pool” performs against a number of relevant policy objectives. The fourth section concludes.

## 2. A Renewable Pool of Contracts-for-Differences

An RE-Pool could provide benefits not just to electricity producers and consumers, but also for the development of the electricity system by providing an efficient hedge for producers and consumers, thus catalyzing contracting for flexibility to bridge the gap between renewable generation and load profile. In the following paragraph, the components of such an RE-Pool are introduced.

### 2.1 Designing the underlying CfD contract

CfDs are an established instrument for de-risking investment into renewable energy installations with ample experience in implementation in countries such as France and the United Kingdom.

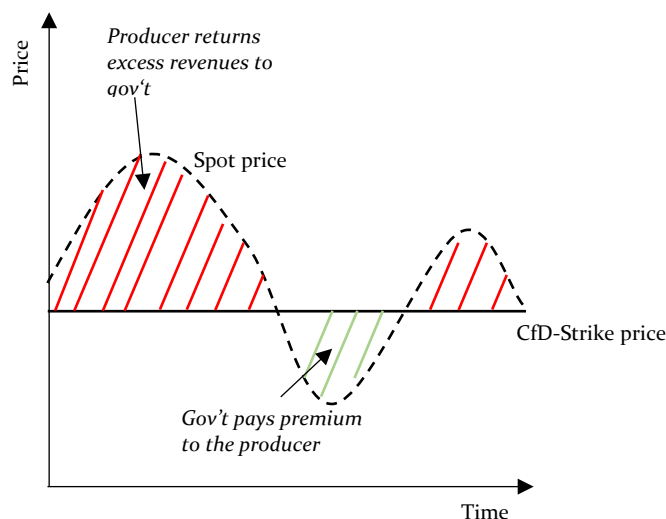


Figure 2 Price hedging function of a CfD for RES-Producers

There remains, however, a debate about the design of the instrument. To allow for a consistent discussion of the combination with an RE-Pool for consumers, we assume the following design elements for contracts for differences and their tender, which are characterized in more detail in Annex 1.

A government mandated and secured agency tenders CfDs. Renewable projects offer a bid that reflects the strike price they desire in a CfD contract. The projects offering the lowest strike prices are granted CfDs. In the auction clearance, a bonus is applied to bids from installations that are system friendly, e.g. PV panels facing east or west. Thus, the plant can win a contract even if it requires a somewhat higher strike price.

The CfD awarded to a wind- or solar-project hedges the project against power price volatility. When the actual power price for the reference period (15-minute or hourly) interval is below the strike price, then the renewable project will obtain a payment for the difference corresponding to the price difference between the strike price and the reference price multiplied by its power production. The reference market is the day-ahead market in the bidding zone.<sup>2</sup> Symmetrically, if the power price exceeds the strike price, the renewable project pays back the difference to the government agency. Thus, the revenue level for the project is stabilized. To ensure the renewable project retains full incentives to respond to spot and balancing market prices, the payments under the CfD are not linked to the produced volume of energy in any 15-minute or hourly time

<sup>2</sup> In a power market design with multiple bidding zones or even nodal prices, the reference market would be the local bidding zone or the local power price, thus ensuring that potential changes to bidding zones or a shift to nodal pricing will not impact viability of projects.

interval where production is curtailed. Instead, in the case that production is reduced due to zero power prices or balancing needs, the production used for remuneration is equal to the available active power that wind and solar projects already calculate as the basis for remuneration in balancing mechanisms by several European transmission system operators (TSOs).

## **2.2 Aggregating RE installations into an RE-Pool**

The standardized structure of renewable energy support through CfDs allows the aggregation of contracts into a “Renewable Energy Pool.” The pool is defined by the sum of production capacities, the aggregated production profile, as well as the strike prices for producers and consumers. As more CfDs from diverse wind and solar projects are combined, the more stable will be the production profile hedged and the more attractive for electricity consumers the RE-Pool will be.

The *volume* of the RE-Pool is the aggregated generation capacity of all installations in the pool. Based on statistics for wind- and solar-generation for an average weather year, the expected annual power production volume for the pooled CfD is calculated. A consumer would obtain, for example, 1 MWh of the pooled CfD. If the total CfDs covered by the pool constitute 100 MWh, then the consumer effectively is hedged with 1% of each of the projects that are part of the RE-Pool.

The share of the RE-Pool that is granted to a firm or a retail company determines the revenue stream the electricity consumer will obtain or be liable for to hedge electricity costs. As the payments are independent from the realized demand of the consumer, they will not distort consumption choices, but preserve incentives that may result from, for example, real-time pricing. If, for example, electricity prices are high in a period, then the consumer is incentivized to reduce or shift electricity demand. The CfD payment for the period is not dependent on this consumption choice and, thus, should not result in distortions. This payment to consumers will coincide with times of high power prices, subsequently reducing the level and volatility of electricity costs to consumers (cf. Section 3.2).

To realize the full benefit of a diversified portfolio and provide a standardized reference product for complementary investments into flexibility, all projects should be included into one RE-Pool and projects in future years should also be added to the pool. Thus, the production profile gradually evolves with the type and location of additional renewables connected to the system. Further, the average strike price for renewable projects in the pool will evolve over time. The cost of new renewables will likely be lower as technology costs fall, but might also rise if less attractive sites must be used. This results in two different design options for consumer pricing. Consumer contracts with the renewable pool could be set at the average strike price set by the renewables added to the pool in the specific year (so called vintage prices). This would lock-in precise hedging price for consumers. Alternatively, consumer contracts with the renewable pool could be set at the average price level of all renewables connected to the pool and might then slightly adjust over time. Importantly, in both approaches the contracts for difference with consumer is based on the production profile of all renewables in the pool. This standardized reference product will help catalyze the development of complementary forward products to unlock flexibility and hedge profile risks for consumers.

## **2.3 Allocating the RE-Pool to consumers**

Access to the pooled CfD will be attractive for consumers as it ensures reliably low electricity prices and climate neutral electricity supply. It can be expected that demand for such a product



would be larger than the supply as long as the additional supply of renewable energy is constrained by land and planning constraints. This raises the question of how access to the RE-Pool should be prioritized.

One option of allocating the shares of the RE-Pool to consumers are competitive auctions in which consumers bid their willingness to pay for the electricity from the renewable RE-Pool. However, auctioning raises the question of who gets access to the scarcity rent from renewable energy to the system. If it is to be allocated to prioritized consumers segments, then the approach will not differ from the prioritized allocation of access to the RE-Pool. If it is to be shared among all consumers, for example by contributing to network costs, then objectives like enhancing local acceptance by ensuring participation in wind projects or international price competitive renewable energy might not be achieved.

Hence it might be suitable to decide *ex-ante* through administrative allocation on what share of the RE-Pool is granted to different user groups and then to follow a suitable protocol for granting this access to a share of the RE-Pool to each individual household and firm:

- 1) *Neighbors to wind-project*: Knauf (2022) finds that reduced electricity tariffs are the preferred manner of obtaining financial benefits as compensation for its construction for neighbors of prospective wind park. Hence it might be advisable to grant households access to the RE-Pool for a share of the electricity produced by a new wind-park in their vicinity.
- 2) *Energy-intensive industrial consumers*: It could further make sense to allocate the renewable production to energy intensive companies, especially those investing in climate neutral production processes. Many current clean industrial processes that are already electrified and most future climate neutral production processes require carbon neutral electricity (directly or indirectly via other clean energy carriers such as hydrogen) and are dependent on moderate and predictable electricity prices. Therefore, to unlock such investments, it is advisable to prioritize access to the RE-Pool to industrial users undertaking these projects. This would entail the side benefit of ensuring strong incentives for realizing flexibility options in the projects to contribute toward matching the demand profile with the renewable generation profile.
- 3) *Remaining consumers*: With the prioritization of access to the above two user groups, during the transition period, only a limited availability of access to contracts for difference for other households and commercial consumers will remain. The access to the remaining CfD-volume could be prioritized to consumers realizing flexibility potentials so as to signal the importance of such flexibility and its operation according to system needs.<sup>3</sup>

In addition to the decision whether access to the RE-Pool would be through auctions or administrative allocation, there are also a number of important design options.

The *exit option* will determine under which conditions firms can opt-out of their obligation to purchase electricity from the RE-Pool. Access to the RE-Pool offers a hedge against potentially high electricity prices, but also entails a liability for payments at times of low electricity prices. Therefore, also the assumed value of this hedge will vary over time. It is important to ensure that consumers will not strategically abandon or interrupt their access to a contract for difference in times when expected electricity prices are low. Therefore opting-out of the RE-Pool needs to be

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<sup>3</sup> For smaller consumers, we propose to do an allocation in terms of fixed energy amounts based on a standardized consumer basis (similar to standardized load profiles), in such a way that more energy consumption by individual consumers does not lead to a larger allocated share of CfD payments. One potential approach is to base this on past years of consumption or on fixed criteria (household size, heating pump, or EV tariffs).

conditional on strict requirements, like the permanent closure of a production process or demolition of a property.

The government agency backing the contracts for differences would serve as counter party for all producers and consumers for contracts and payments under the contract. Large consumers would be allocated delivery of the renewable pool and directly pay/receive payment from the pool, based on a fixed amount of energy, much like how financial hedges are concluded. For households and smaller industrial and commercial consumers, the retailer they select would be granted the access to the RE-Pool where the allocated volume based on historical consumption of the consumer (thus preserving incentives from short-term price signals). If consumers change their retailer, the RE-Pool access would change accordingly. The payments would be made through the retail firms that include the RE-Pool contracts in their risk management according to the share of the RE-Pool granted to consumers.

Industrial consumers often need to be able to demonstrate usage of green electricity to investors or their clients. Hence it will be highly valuable if the *green attribute* of electricity production hedged by an RE-Pool is also passed on to those consumers in the pool (Köveker et al., 2023).

### **3. Assessing the potential of an RE-Pool**

Project developers require long-term contracts to finance wind- and solar projects. This is because the power prices expected over the next twenty years are highly uncertain and, hence, the value of electricity from wind- and solar-power is equally uncertain. Consequently, it is not possible to access low-cost finance (debt or bonds) with such uncertain revenues. Relying largely on equity to fund projects in general would strongly increase renewable costs because financing costs and, hence, costs of delivering energy might double. Thus, project developers require long-term contracts that secure the price at which the project can sell electricity to secure financing.

In the past, this was of less concern because renewable support mechanisms provided the desired revenue stability. When renewable technology costs were higher and power prices lower, renewable projects were only viable with such public support mechanisms. Thus, the revenue from these support mechanisms was used to secure access to low-cost financing (Neuhoff, Richstein and May, 2022). Unfortunately, public support mechanisms have, in many countries (with sliding or fixed market premia), been designed in a manner that secured a minimum revenue level to projects while allowing projects to retain the profits from extremely high prices.

Therefore, it is now commonly agreed that long-term contractual arrangements need to be designed in a symmetric manner, so as to secure power producers against the risk of low prices and energy consumers against the risk of high prices. Two main options exist for these symmetric contracts. First, bilateral contracts between power producers and consumers, which are typically referred to as Power Purchasing Agreements (PPAs). Second, Contracts for Difference (CfD) that have, according to the above policy suggestion, been aggregated into an RE-Pool that is then awarded to consumers. Given that both types of contract can be structured in various forms, their main difference lies in their counter party and the government's ability to pass on the conditions of a CfD to consumers.

In the following subsections, we assess the RE-Pool's potential to address the five policy objectives of (i) catalyzing the required increase in renewable energy capacity; (ii) lowering financing costs; (iii) reducing the volatility of renewable energy supply; (iv) providing incentives for system-friendly installations; and (v) supporting the development of flexibility projects.

### 3.1 Expanding wind- and solar energy capacity

PPAs are now very prominent in the political debate with project developers, consultants, and commercial consumers across the EU attempting to scale up the use of PPAs for new projects. Historically, PPAs have been primarily used to back small-scale investments for, typically, 5-year lifetime extensions of existing wind projects and in countries providing renewable support using tradable green certificates (Sweden, early years in UK). However, earlier analysis shows that the demand for PPAs from commercial consumers and energy companies will be insufficient to back the scale of wind- and solar-investments required to reach the EU 2030 targets (May and Neuhoff, 2019). This is because energy companies and commercial users take a large risk if they underwrite a PPA with the required contract duration of 20 years: their customer base could shrink or their production facilities could close. While the company may benefit for the remaining contract time if power prices are higher than reflected in the PPA, it can equally incur losses if power prices are lower (May and Neuhoff, 2021). Consequently, rating agencies treat PPAs as imputed debt in their credit rating by adding the value of the long-term contract to a company's liabilities which raises the debt-equity ratio of a company (Baringa, 2013; Standard and Poor's, 2017).

In the following, we apply the methodology of rating agencies to assess the maximum scale of PPAs companies may be able to underwrite (Figure 2). For this we assume that half of the PPA's financial volume is considered as additional debt and that companies are prepared to underwrite PPAs with an undiscounted payment liability at the scale of half their market capitalization.<sup>4</sup>

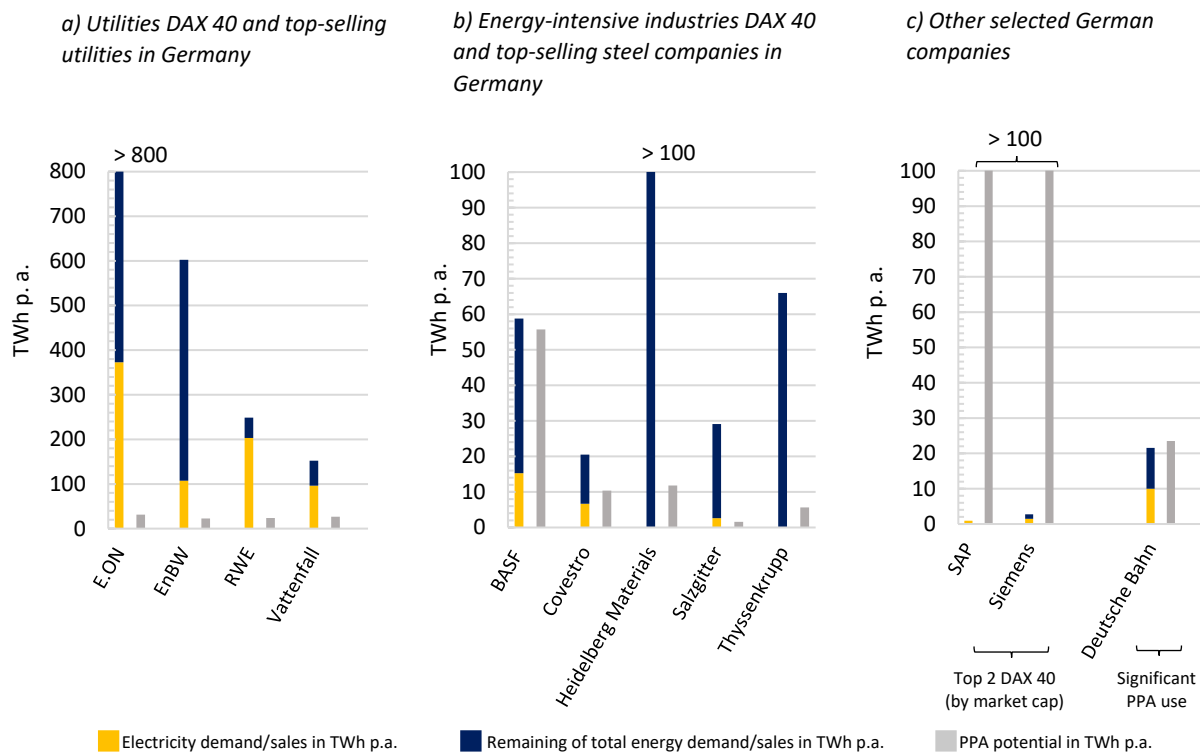


Figure 2 Energy demand and PPA potential for selected companies in TWh p. a. in 2021

**Annotation:** Own illustration based on and company's financial and sustainability data for FY 2021. For detailed assumptions of calculation and data basis, please refer to Appendix 4.

<sup>4</sup> This equals an increase in their debt-equity-ratio of 0.5, if long-term-debt and market capitalization are considered for this ratio. For detailed assumptions, please refer to Appendix 4.

We find that energy utilities can only underwrite PPAs at the scale of 4 to 18 percent of their energy demand. They could, in principle, get the PPAs “off their books” again, thus increasing the total scale of PPAs they can write, if they were to sign corresponding long-term contracts with their consumers. Only large industrial consumers can underwrite such long-term contracts with utilities or directly underwrite long-term PPAs. We find that technology companies, like SAP or Siemens, can potentially safeguard their energy demand with long-term PPAs because their energy costs and, therefore, risk exposures are very small compared to market capitalization. For energy intensive industries, energy costs are high compared to margins, profits, and market capitalization. Hence, they are again constrained and can only underwrite PPAs at the scale of 5 to 51 percent of their total energy need.<sup>5</sup>

If all utilities as well as industrial and commercial consumers considered here were to realize the maximum value of PPAs they could underwrite, this would still only allow to cover 30 percent of their energy needs (consumption weighted), far below the envisaged additional renewable investments envisaged for the coming years. However, it is highly uncertain whether, beyond initial firms and lighthouse projects, commerce and industry have the capability and motivation to engage in such a PPA strategy. Furthermore, experiences during the energy crisis confirmed market participants’ expectations that governments will intervene to protect firms against extremely high power-prices. Thus, it is highly unlikely that commercial and industrial firms are prepared to bear the risk involved in PPAs at times of low power prices, if governments provide some insurance against high power prices.

For energy intensive firms with limitations to the scale of PPAs they can hold on their books, a renewable deployment strategy focused on PPAs implies that they will be excluded from the potential benefits renewables can offer for price levels and hedging as well as limited in accessing green electricity that may be necessary to reach net-zero targets. Public guarantees for PPAs are being discussed but will not address this shortcoming, because a guarantee for a contract will only help the counterparty to the contract, e.g. the renewable project, to deal with limited creditworthiness of the industrial consumers, but will not address the financing implications for the industrial consumer itself.

Meanwhile, supporting the energy transition via government-backed CfDs would avoid the drawbacks of PPAs for private companies. For this, the aforementioned design of the exit clauses is key. These need to ensure that, on the one hand, companies do not face the risk of having to purchase electricity for retail customers that have already changed utilities or procuring electricity for production processes that have been closed down due to unforeseen events. On the other hand, however, it is important that companies cannot strategically abandon their obligations in times of low power prices.

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<sup>5</sup> BASF is a special case in this respect and is excluded in this number, as it has a broader product portfolio. Although most energy is consumed for the production of basic chemicals, this only accounts for about one-fourth of total revenue (in 2021). Hence, the sales of other less energy-intensive product lines, including performance products like plastics, coatings, and catalysts, can cushion the energy price risk of the production of basic chemicals.

### **3.2 Reducing financing risks to reduce costs for consumers**

With two contracting options available in principle to back (some of) the investments in renewable technologies, we now discuss their implications on the cost for financing of projects and, thus, ultimately the costs for energy consumers.

First, the duration of contracts matters because it determines the duration for which debt can be raised and, therefore, the scale of equity with higher returns that is required to fund a project. In principle, PPAs and CfDs can be signed for similar time frames of 20-25 years. In practice PPAs are often signed for shorter periods, thus inherently resulting in higher financing costs.

Second, for investors and lenders to the project, the counter party to a long-term contract matters. Typically, government backed CfDs are significantly more credible for investors than private backed PPAs. An earlier analysis of the impacts for financing costs comparing the situation across EU member states with different support mechanisms found that increased risks will result in an increase of financing costs and, thus, average renewable generation costs of about 10% (May and Neuhoff 2021).

Third, private counter parties to long-term contracts typically have to take the long-term PPAs on their books and will, as discussed in the previous section, be seen as taking a risky position that increases their leverage, thus reducing their creditworthiness and implying higher financing cost for the firm. This increase in financing costs translates in an overall cost increase of about 20% in comparison to CfDs (May and Neuhoff, 2021).

Thus, by building on CfDs, the RE-Pool could become a source of reliably affordable electricity to customers, providing renewable electricity at a lower cost than could be provided by signing individual PPAs.

It is being discussed, whether to address some of the disadvantages by providing public guarantees to private PPAs. This should, in principle, reduce the increase of financing costs for wind projects, thus eliminating third of the aforementioned 30% increase of costs per renewable energy delivered in a PPA compared to a renewable pool setting. However, enhancing creditworthiness through state guarantees can generate economic disincentives and create a moral hazard problem, whereby riskier contracts may be pursued due to the assurance of state intervention in the event of negative outcomes. This can result in companies pursuing risky business models, which can lead to instability in the energy market, undesirable incentives for industrial production, and high costs for the state budget. In essence, the state guarantee provides a safety net that could encourage irresponsible risk-taking behavior or even gaming by energy utilities and industrial companies, with large financial risks for the overall economy (see detailed options in Annex 1).<sup>6</sup>

### **3.3 Ensuring full incentives for system friendly wind and solar projects**

As wind- and solar production profile differs from the typical demand profile, flexibility in the energy system is critical for matching demand and supply. Wind and solar projects can contribute to this flexibility through their technology choice and by diversifying their locations.

#### **3.3.1. Technology choice**

With increasing volumes of wind- and solar-power connected to the system, the value of electricity will be lower in sunny periods, e.g. at mid-day, and windy periods, while being higher in other periods where the overall production of renewable energy is low. Therefore, it will be

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<sup>6</sup> For more concrete examples on this, please refer to Appendix 1.

increasingly valuable if solar panels are also oriented toward the east and west to provide more of their production in the morning and afternoon, as well as if wind turbines have relative to generation capacity longer blades to increase the share of the power output in periods of lower wind speeds.

Electricity markets do, in principle, reward such investments as electricity prices are expected to be relatively higher in periods with less solar radiation and lower wind speeds than in other periods. In practice, the challenge for investors is that this effect will increase with the share of wind- and solar-power connected to the system, thus being far stronger in the future than today. Therefore, the value of the investment is heavily discounted by industrial and commercial consumers at the moment of signing a PPA since they put a higher weight on the higher electricity costs at the beginning of the project's lifetime. Therefore, project developers have to back any additional costs involved in system friendly design of wind- or solar-projects with equity leading to higher financing costs. Thus, PPA-structures will provide some, but not sufficient, incentives for system friendly design of projects.

Meanwhile, the CfDs allows for incentives for system friendly designs to be incorporated in the auction design.<sup>7</sup> During operations, the CfD ensures the project obtains the same price per MWh electricity that it can deliver, thus revenues during operations will not provide incentives for system friendly design choices at the time of investments. However, a variety of options are available to ensure adequate incentives for system friendly design in the auction clearing mechanism through different types of bonus-and-penalty systems (Neuhoff, May and Richstein, 2019). For example, a bonus could be applied to bids submitted by solar panels oriented toward the east or west so that these bids can win in the tender despite their higher costs per MWh of electricity produced. Therefore, it is possible to ensure that project developers incorporate the full value of a system friendly design for the energy system in their bids.

Uncertainties about the future development of the power system will translate into uncertainties in the calculation of the bonus or malus function to be used in the CfD tender. In a PPA approach, private actors have to pursue the assessment and are individually exposed to the benefits and costs – in principal an attractive feature. In the suggested CfD approach, public actors have to design the bonus and malus, with energy users as a whole exposed to the costs and benefits of getting it right or wrong. The public design of the bonus and malus system offers the advantage that it can be adjusted for each new tendering round to respond to results and insights gathered from preceding tenders. The private incorporation in PPA structures offers little opportunity for public policy makers to correct for, for example, insufficient weight put on system friendly design due to high discounting on uncertain revenues in the second decade of project operation.

### **3.3.2. Location**

The choice of locations for new wind- and solar-projects in many cases presents a trade-off since it not only matters for the number of potential full load hours that are possible, for example at more windy sites, but will also influence the required additional transmission investment, for example if these windy sites are located far away from load centers. Furthermore, more diverse locations will result in a more stable aggregate production pattern of wind- or solar-power within a country.

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<sup>7</sup> Alternatively, incentives can be set by using yardstick mechanisms, such as the one suggested by Newbery (2021). These work similarly to the incentive design of PPAs, but consequently are likely to suffer the same drawbacks.

In principle, an efficient power market design should provide project investors with the correct incentives for a suitable spatial distribution. In practice a variety of factors will inhibit an efficient outcome. For instance, prices for delivered electricity do not reflect the local value as long as the prices are set within regulated pricing zones such that producers do not see the costs and benefits of production at a specific location in terms of short-term operation (e.g., re-dispatch) and additional transmission investment needs in the long-run. Furthermore, available sites for wind- and solar-projects at the locations with the best resource potential are likely to be scarce in many countries. As a result, the price in a (perfect) market equilibrium for energy delivered from projects at such sites includes the scarcity value of such sites and, therefore, could result in significant scarcity rents for owners of the suitable land.

Thus, in practice, countries with inhomogeneous resource potential, like, for example, the on-shore wind potential in Germany, have implemented mechanisms to adjust the price level to the local resource potential for decades. This reduces – and could in principle even mute – the incentives (e.g. scarcity rents) to move to the best locations while also allowing investments at sites with weaker resource potential. Such a differentiation has been implemented in the auctions for sliding premia, and can also be implemented in tenders for CfD (Kröger, Neuhoff and Richstein, 2022b).

In contrast, bilateral PPAs – in principle – do not allow for such a differentiation in the tender process. Thus, in the absence of locational pricing and differentiated grid connection charges reflecting investment costs, these might provide inaccurate incentives and could result in scarcity rents of best sites captured by project developers and land owners, thus resulting in increases in energy costs to consumers.<sup>8</sup>

### **3.3.3. Operation**

During the lifetime of the projects covered by the RE-Pool, incentives for the system friendly operation of the installations are important. A standard CfDs will provide the correct incentives for system operation, if it ensures that CfD payments or liabilities are continued during periods in which production is reduced below full capacity in response to network constraints, offers to the balancing market, or spot prices declining below variable costs. TSOs have already established standard procedures in the context of imbalance markets (see Annex 3d).

PPAs with private counter parties would also require such provisions to ensure appropriate incentives. The inherent intransparent nature of such contracts limits the ability of public entities to ensure such provisions are reflected in contracts and their execution. Less important for wind- and solar-projects are incentives for availability. In principle it is desirable to ensure accelerated repair of turbines or solar panels if power prices are high and scheduling of maintenance in periods with low power prices. In practice, availability is extremely high and maintenance of individual turbines or panels will have limited impact on total availability and is inherently determined by seasonal and weather conditions. Hence such incentives are likely of very limited practical relevance.

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<sup>8</sup> Should grid access for new projects be granted both for projects backed by CfDs and by PPAs, then in countries with significant variations of resource potentials, it may be necessary to use other mechanisms, such as locationally differentiated connection charges, to avoid the creation of excessive land rents or inappropriate locational incentives for PPA backed projects.

### 3.4 Ensuring reliably stable electricity supply

The RE-Pool is an attractive hedging option for consumers because the pooled CfD offers a hedge with lower variance in production volume compared to individual PPA contracts. This is due to both geographical and technological diversification. Thus, they will have less need to balance fluctuating energy volumes from the pool with unhedged spot market purchases or additional contracts, as compared to individual PPA contracts.

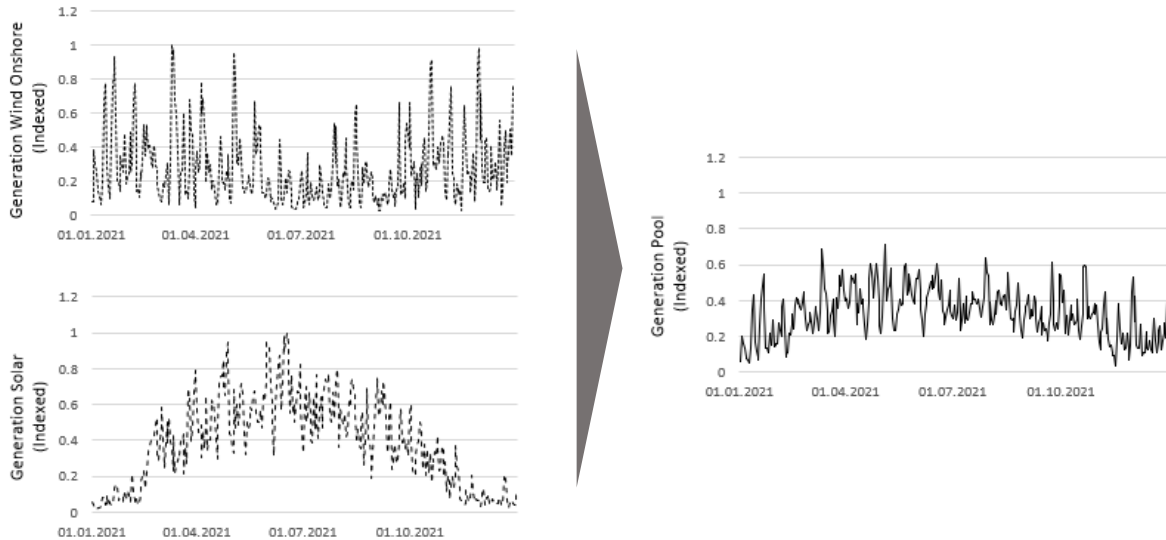


Figure 3 Generation profile of individual technologies and of the pool

First, the RE-Pool provides technological production smoothing due to the difference in production times of solar and wind energy. Figure 4 illustrates this, showing the daily production volumes of onshore wind- and solar-energy in Germany in 2021 indexed to their maximum production in the left-hand panel. The solid line in the right-hand panel indicates the indexed production volume of a pool comprising both production technologies. The pooling already reduces the standard variation of indexed daily production from 0.21 (wind) and 0.26 (solar) to 0.13.

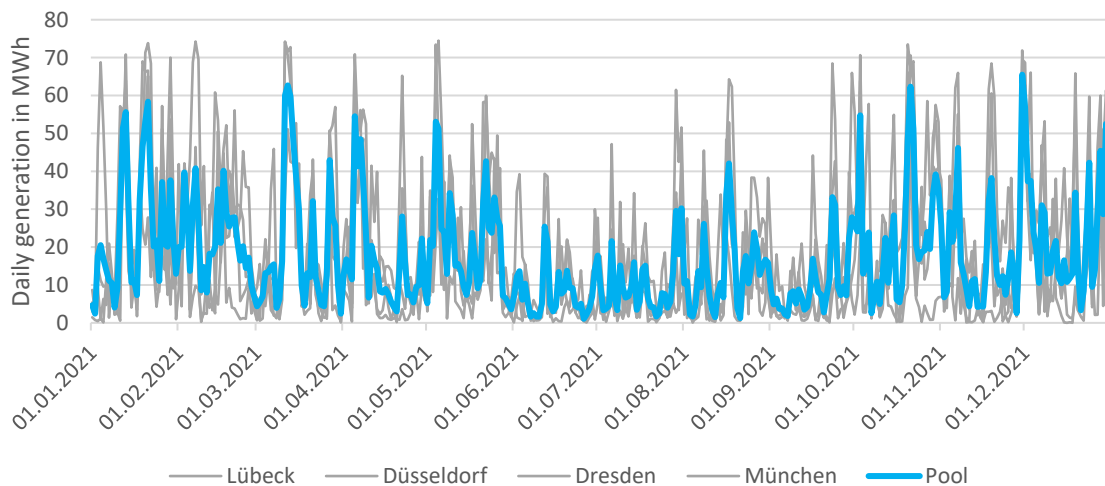


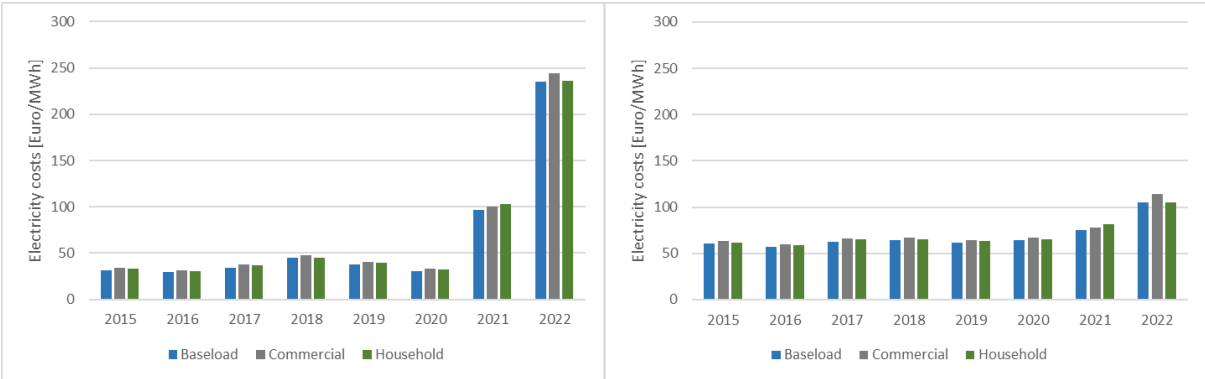
Figure 4 Effect of geographical smoothing of electricity generation



Second, the RE-Pool reduces the variance through geographic smoothing. The production of renewable energy varies across geographies due to varying weather conditions. This is especially true for larger countries. The grey lines in *Figure 5* show the generation of a standard wind turbine at four locations in the north (Lübeck), south (Munich), east (Dresden), and west (Düsseldorf) of Germany in 2021. The blue line is the generation of a pool that consists of wind installations divided equally across all four locations. Relative to the mean output, pooling reduces the variance of the daily power generation by 35% compared to the individual installations.<sup>9</sup> If the previously discussed incentives for the installations of system-friendly turbines are integrated into the support regime, this would result in an even smoother output curve.

Large and solvent electricity consumers might already be able to achieve a similar diversification by combining a large number of PPAs. However, as argued above, most companies are not able to undersign PPAs for their electricity demand; thus the RE-Pool allows for a larger variety of firms to diversify.

In the following, we quantify the stabilizing effect that the RE-Pool would have had on the electricity expenditures of different consumer types (baseload, commercial and private households), based on historical data from 2015 to 2022. We assume that the consumer types have a contract with the RE-Pool that covers 100% of their energy demand in an average year – but provided as the aggregated renewable profile across all onshore wind, offshore wind, and photovoltaic installations in Germany (cf. Section 2). Hence, consumers are hedged, but not completely as a basis risk (difference between their own profile and the renewable pool) remains. For comparability of results, we assume that all contract types are concluded at their fair market price over the entire period.



*Figure 5* Unhedged wholesale electricity costs (left panel), with costs hedged full RE-Pool coverage (right panel)

In *Figure 6* we compare the yearly electricity expenditures of unhedged demand as compared to demand hedged by the pool. As is visible, the RE-Pool by itself already provides a good hedge against electricity cost risks, reducing the volatility from around 344% of average expenditures for 2022 to 153% of average expenditures for 2022. As compared to a simple baseload contract covering 100% of demand (cf. *Figure 7*), the volatility of electricity via the CfD hedge is higher, as the baseload contract secures expenditures in 2022 to 106% for private households and 108% for commercial profiles, while it perfectly hedges baseload consumption (see Appendix 5).

<sup>9</sup> See Appendix 2 for a description of the methodology used in this quantification.

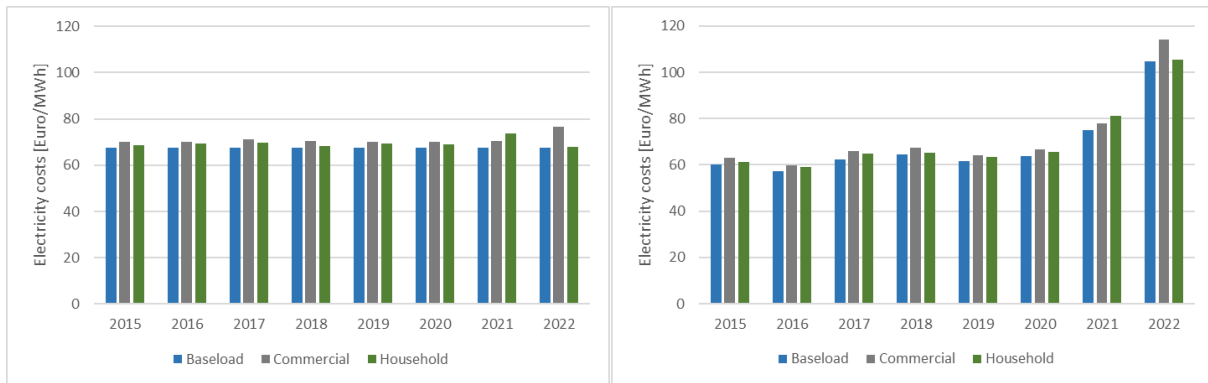


Figure 6 Hedge via a baseload contract (left panel) and via the RE-Pool (right panel)

### 3.5 Unlocking flexibility in the system

The energy transition requires the rapid built up of flexibility options in order to balance the variability of renewable energy production.

However, despite many efforts to introduce new products, liquid trade in forward and future markets only exists for base and peak load contracts. This inhibits the realization of flexibility potentials required in a power system with increasing shares of renewables and rapidly declining availability of gas power generation as traditional flexibility provider: Without forward products reflecting the characteristics of flexibility (load shifting or storage), providers of complementary flexibility have no market to hedge the value they can offer to the system. Without reliable revenue streams and forward markets to align demand and supply, investments to unlock flexibility potentials are difficult to realize.

Furthermore, as electricity prices are so far hedged with base- and peak-load contracts, a consumer that fails to unlock flexibility potentials does not bear price risks. Thus, in the current system, for the consumer, realizing flexibility potentials is not a risk reducing activity, but merely an uncertain revenue potential that is additional to their core business, and hence not pursued with priority.

Instead, flexibility is so far advanced by renewable remuneration design components that incentivize storage and load shifting to maximize self-consumption of prosumers or storage at the wind production site. This reinforces the narrative of complementing wind- and solar-power generation with local flexibility elements to turn them into base load production. It fails to unlock the large flexibility potential of large energy users and to realize the vast pooling benefits of the integrated European power system with strategically placed flexibility resources (in terms of grid locations).

A step change is required that involves:

- Exposing electricity users to the profile risk – e.g. the risk that their electricity demand profile is not aligned with the power generation profile of wind- and solar power (profile risk).
- Thereby incentivizing consumers (i) to realize flexibility potentials to physically hedge against the profile risk to the extent possible in an economical fashion; and(ii) to purchase hedges for the remaining profile risks, thus creating stable revenue streams that allows third parties to realize flexibility potentials.

The allocation of the RE-Pool to consumers (and retailers on their behalf) can trigger this step change. The Pooled CfD provides a hedge for power prices with a profile of the wind- and solar

power generation. By being independent of the actual consumption, but instead of the production of renewables, short-term incentives to respond to electricity prices are maintained.

Thus, the consumer is incentivized to acquire hedges (or realize flexibility potentials as a physical hedge) to bridge the gap between its load profile and the renewable generation pool profile, as power price risks are not fully hedged with an RE-CfD-Pool (cf section 3.4).

A typical hedge, which might evolve in future, could be an intraday hedge, for the average price difference between the 4 hours with highest power prices and 4 hours with the lowest prices. This would match the characteristics of a typical physical underlying process (i.e. batter storage or load shifting demand response), thus minimizing risk while facilitating financing of flexibility investments.

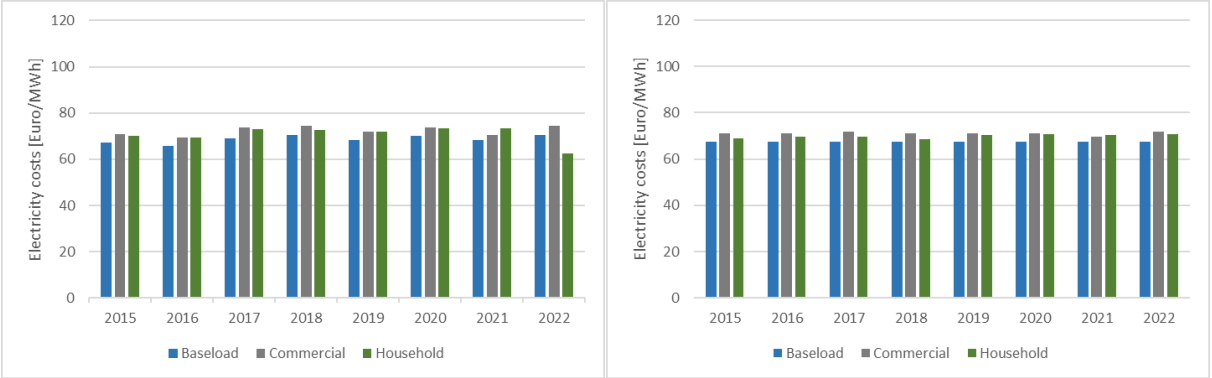


Figure 7 RE-Pool Hedge plus optimal 4-hour-price spread hedge (left panel), optimal base- and peak-load hedge

As can be seen in Figure 8 (left panel), even such a simple hedging combination of an RE-Pool with a fairly priced “4 hour product” (concluded for around 33% of yearly energy consumption) can strongly reduce volatility: the worst year has only 103% of the average electricity consumption cost. This nearly matches the volatility achieved for optimal combination of the currently dominating base- and peak-load contracts (right panel, where the worst year has costs around 101% of average electricity consumption).

An element that warrants further analysis is whether established approaches to adjust the remuneration to the realized wind patterns, as currently part of, for example, the tenders for the sliding market premium, should also be adapted. This can reduce risks resulting from imprecise wind forecasts during the planning stage or from new neighboring wind-parks reducing the wind speed.

#### 4. Conclusion

Long-term contracting arrangements are required for renewable deployment as public support mechanism ensuring an adequate remuneration level are phased out. We compare two main options available – private bilateral power purchasing agreements and a renewable pool based on contracts for differences with both producers and consumers of the renewable energy.

This paper illustrates that pooling both across technologies and geographies can lead to significantly lower volatility in electricity generation. It then assesses how a renewable pool affects consumer’s volume risk and how a combination of a CfD with a simple hedging product is already very effective at hedging electricity consumers against price fluctuations. Combining these assessments with results from the literature, we find that the RE-Pool offers a number of benefits when compared to a setting focused on PPAs.

First, a renewable pool contributes to a stable project pipeline for investment into renewable energy. Second, it has lower financing costs than the expansion of renewable energy through PPAs. Third, the tender design for CfDs under the renewable pool offers options for adequately incentivizing system-friendly deployment of renewable energy while incentives for system friendly design are largely discounted in PPA arrangements. Fourth, the pooling can reduce the volatility of the profile that is hedged with a renewable pool compared to individual PPAs signed by consumers. Finally, the RE-Pool provides incentives for investing into flexibility products that can catalyze the development of such products on financial markets. These arguments speak in favor a central role for an RE-Pool when reforming the current European electricity market.

A set of elements warrant particular attention in the design of a renewable pool. First, changing the support system for renewables to CfDs only provides a stable pipeline for investments as long as the government has an interest in underwriting additional CfD-projects. However, past experiences show that governments that are hostile to renewable energies have many levers from adjustments to planning processes, grid access rules, charges, and taxes to outright moratoria on further deployment. Second, in order to avoid the negative effects of PPAs on capital costs and credit ratings, it is important that the exit-option for participating firms is well designed while at the same time not offer any incentives for gaming the systems (e.g., firms should not be able to back-out of their obligations in times of low energy prices). Finally, in the initial years, the volume of new CfDs underwritten in tenders may not meet the demand of industry and household consumers. The allocation of the RE-Pool to consumers will raise debates regarding those groups that are granted access to the attractive instrument and it will be important to agree on objective and fair criteria. To reduce any such tensions, opportunities to broaden the available renewables in the pool should be explored. A rapid implementation, broad coverage of all wind- and solar-projects, and cooperation with neighboring member states will be critical.

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## Appendix 1: Examples of gaming opportunities from public guarantees for PPAs

In the following we describe three illustrative gaming opportunities that might emerge for contract parties, if public guarantees are provided for long-term PPAs:

**PPAs as a subsidized option contract for electricity retailers: Public guarantees could encourage a risky and highly profitable business model.** An electricity supplier purchases many government-backed PPAs. If the wholesale electricity price turns out to be high, then the electricity supplier can pay out high profits to shareholders because it has purchased electricity cheaper than its competitors. If wholesale electricity prices turn out to be low, then the electricity supplier cannot pass on the PPA prices to its end customers, goes bankrupt, and the government has to step in via the guarantee. If the profits from periods of high power prices exceed the set-up or acquisition cost of a retail business, then such a strategy is viable.

**PPA as a state-funded closure premium for industrial consumers:** A PPA is signed between a wind project and an industrial company. If the wholesale electricity price increases significantly in future years, so that certain basic production processes are no longer economical at this electricity price, then the industrial company and the wind project dissolve the PPA. The wind project benefits because it can sell the electricity at higher prices. It pays part of this additional revenue to the industrial company as a decommissioning premium. In this case, no payment is granted or necessary from the public guarantee. If, however, on the other hand, the wholesale electricity price falls significantly so that production is no longer economical with prices under the PPA contract, then the production site is (temporarily) closed. A legal successor then resumes operations and purchases electricity at lower prices. The state pays the difference between the wholesale electricity price and the PPA contract price to the wind project.

**PPA as opportunity to play with time horizons:** An industrial company enters into a 20-year contract with a wind project, where the contract price is low at the beginning and then increases continuously. The industrial company thus receives very cheap electricity for the first ten years. If it then decides - because plants have been depreciated or because the contractually relevant electricity prices are then too high - to cease production and can no longer satisfy the contract, then the state must reimburse the difference between the wholesale electricity prices and the then high contract prices of the PPA in the second ten years.

## Appendix 2: Quantification of volume risks

### A. Technological smoothing

To illustrate the effect of technological smoothing we downloaded the daily generation volumes for onshore wind and solar power from the ENTSO-E transparency platform for the year 2021 (<https://transparency.entsoe.eu/>). We then calculated the indexed production volume as the share of the maximum generation volume that is achieved by the technology at each day. For onshore wind power the maximum generation volume was achieved on March 11 and was equal to 3.55 GWh. For solar power the maximum generation volume was achieved on June 14 and was equal to 1.29 GWh.

We then calculated the indexed output of the pool as  $\frac{Wind\ Output_t + Solar\ Output_t}{2}$  and calculate the variance of output for all three indexed production series.

## B. Geographical smoothing

In order to calculate the effect of geographical smoothing we focus on the case study of onshore wind study in Germany. Input to the calculations are the ERA-5 weather reanalysis data (<https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5>) and the power curve of the Enercon E-115 turbine available as part of the BReeze R package (<https://cran.r-project.org/web/packages/bReeze/index.html>).

We select four locations at opposite ends of Germany that are located close to well-known cities for the purpose of illustrating the effect of geographic diversification. Specifically, the locations are:

- Close to Lübeck (54°N, 10.5°E)
- Close to Düsseldorf (51°N, 6.5°E)
- Close to Dresden (51°N, 14°E)
- Close to Munich (48°N, 11.5°E)

We use the wind data at each location to perform a simplified calculation of hourly wind output mapping the power curve values to the wind speeds in each hour and assuming an average availability of 97% with an equal probability of unavailability at each hour. We then calculate the output of the pool as the average of power output at each of the location. The summary statistics from these calculations are displayed in *Table 2*.

*Table 1* Production at different locations

	Lübeck	Düsseldorf	Dresden	München	Pool
<i>Variance</i>	393.6	317.1	262.5	170.1	188.1
<i>Mean (in MWh)</i>	24.7	18.2	16.6	10.1	17.4
<i>Sum (in MWh)</i>	9014.0	6660.5	6041.3	3689.4	6351.3
<i>Variance/Mean</i>	15.9	17.4	15.9	16.8	10.8
<i>Relative Reduction in Variance</i>					35%

## Appendix 3: CfD Design Options

In the following, a number of relevant design options relating to CfDs are introduced and discussed.

### a. Strike price

The *strike price* of a CfD is the price that the producer is guaranteed for each hour of production. It can be determined through auctions or administrative procedures.

In order to achieve efficient incentives for the investment into new installations, the strike prices can be augmented with additional policy instruments. For instance, the German Reference Yield Model that modifies remuneration depending on the location of the wind turbine could be applied (Kröger, Neuhoﬀ and Richstein, 2022a). To ensure system-friendly design choices, in the clearing process of the tender, installations could obtain a bonus or malus reflecting the expected market premium/malus a wind or solar project would obtain at the location compared to an average wind or solar project at the location (May, 2017).

### b. Reference market and period



The *reference price* is the price that the strike price is compared to in order to determine the payments made under the CfD. The choice of reference market and period are important since they determine the incentives for production.

The *reference market* should be the most local price available at the connection point at any time in the contract in order to hedge producers against politically decided changes to pricing zones and regimes. The market from which the price is taken is referred to as the reference market. In the current market structure this would be the bidding zone wide price. If there is further market splitting or nodal pricing in the future, the local price would serve as reference price.

The *reference period* for which the reference price is calculated should likewise be the most frequently quoted price that is available to the regulator (e.g., currently quarterly hour day ahead electricity price in Germany). In a future with for example additional intraday or real-time auctions, the reference price could move closer to real time.

#### c. Contractual volume

The *contractual volume* is the quantity over which the CfD payments are calculated. The CfD should cover the full available power production of a wind or solar project. As long as reference market is the day ahead market, wind and solar projects wind and (large) solar installations would be required to measure and report via aerometers or irradiation sensors the potential production volume as it is required by the current German renewable energy act. Such monitoring ensures market participants will not deliberately withhold some output to escalate prices in the real time market. Alternatively, these could be directly used as the reference volumes, with clauses for strong deviations from actual production.

#### d. Curtailment and balancing market participation

As Europe moves toward 100% renewable energy it is important to ensure wind and solar projects respond to negative prices and participate in balancing markets (downward regulation). The CfD should be designed so as to avoid distorting such incentives. Therefore, we would propose to disconnect the CfD payments from the response of a wind and solar project to spot prices and balancing markets. If output is reduced below the available active power in response to spot market signals, this should not alter the remuneration (or liability) under the CfD. For this, one can built on existing measurements of Available Active Power already applied by TSOs like TenneT, 50 Herz, Energienet and Eirgrid for balancing market purposes. These measurements could be used as reference point for CfD remuneration in instances when an available wind- or solar project reduces or stops production in response to price signals.<sup>10</sup>

For the RE-Pool this implies a liability for CfD payments during periods in which the contracted projects reduce their production. This additional liability would need to be added to the strike price of the RE-Pool granted to consumers. It will not increase the cost of the RE-Pool for electricity consumers, because project will no longer have to add a reserve margin in CfD tenders to account for risks forgone revenue during periods of zero prices and revenues.

#### e. Volume risk and hedging contracts

By fixing the price at which energy producers are remunerated, CfDs address an important uncertainty regarding a project's revenues. This security in sales prices can lead to a lower

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<sup>10</sup> See section 6, "Baselining options for wind and solar PV" in Elia (2021) Baseline methodology assessment, available at [https://www.elia.be/en/public-consultation/20210927\\_public-consultation-of-the-study-on-baseline-methodologies](https://www.elia.be/en/public-consultation/20210927_public-consultation-of-the-study-on-baseline-methodologies)

variance of a project’s revenue, depending on the correlation between the project’s sales price and volume. Nevertheless, a valid critique of contracts for differences is that they leave volume risks with the producers since weather patterns imply that wind production volumes can vary by more than 10% between years. To address these variations within the CfD design would complicate contract structures.

Hence, we propose to replicate the approach common in North America where projects are hedged with CfD-type structures and use weather derivatives to hedge volume risks. Large insurance companies are comfortable to underwrite such derivatives as their exposure can be calculated with standardized models, are free of regulatory risk and weather is largely uncorrelated with macroeconomic development leading to a diversification effect of portfolios. Furthermore, consumers hedged with the RE pool will also be interested to be the counter party to such weather hedges as they are negatively correlated with the value of the RE-Pool with respect to periods of unusual high or low wind production or solar radiation volumes. A balance of demand and supply has the advantage that potential risk premia are avoided that financial actors would charge for taking such exposure.

**Appendix 4: Assumptions on PPA calculations**

The figure in chapter 2 is based on the following assumptions:

- It is assumed that companies' sign PPAs at a scale that results in the financial leverage quota (market cap to long-term debt) increasing by the factor 0.5.
- Half of the future cash flows of the PPAs are classified as long-term liabilities by rating agencies.
- For the assessment of the energy demand that can be met with PPA contracts, both electricity and other energy demand are considered. This is motivated by the assumption that the non-electricity energy input will have to be largely be substituted by green electricity in the future. The factor at which non-electric energy is substituted by electricity can be larger or smaller than one dependent on the energy usage. We assume an average factor of one.
- For energy utilities, the actual "sold" energy volumes are considered (not only own generation), which also includes possible external purchases.
- The PPA price per MWh is assumed to be 50 Euro.
- The contract duration assumed here for the PPA is 20 years.
- The cash flows have not been discounted for a simplified presentation.
- All financial and sustainability data of the selected companies refer to the FY 2021.

Based on the assumptions stated above, the PPA potential in GWh p. a. can be calculated as follows:

$$\frac{\text{Market cap}}{(20 * (\frac{1}{2} * 50.000 \text{ EUR/GWh}))} * 0,5$$

The market cap of the companies has been taken from YCharts data for the year 2021 (end of December), available at: <https://ycharts.com/>. The data is given in USD and has been converted to EUR by the corresponding exchange at the given time.

Other relevant information for the selected companies, has been taken from the following company reports and websites:

Table 2 Sources of company information

Company	Reports /Websites
BASF	<a href="https://bericht.basf.com/2021/de/_assets/downloads/entire-basf-gb21.xlsx">https://bericht.basf.com/2021/de/_assets/downloads/entire-basf-gb21.xlsx</a>
Covestro	<a href="https://bericht.covestro.com/geschäftsbericht-2021/serviceseiten/downloads/files/entire-covestro-ar21.pdf">https://bericht.covestro.com/geschäftsbericht-2021/serviceseiten/downloads/files/entire-covestro-ar21.pdf</a>
Deutsche Bahn	<a href="https://ir.deutschebahn.com/fileadmin/Deutsch/2021/Berichte/DB_IB21_web_03.pdf">https://ir.deutschebahn.com/fileadmin/Deutsch/2021/Berichte/DB_IB21_web_03.pdf</a>
EnBW	<a href="https://www.EnBW.com/integrierter-geschäftsbericht-2021/">https://www.EnBW.com/integrierter-geschäftsbericht-2021/;</a>
E.ON	<a href="https://sustainabilityreport.eon.com/en.html">https://sustainabilityreport.eon.com/en.html</a> ; <a href="https://archiv.geschäftsberichte-download.de/2021/ENAG99.pdf">https://archiv.geschäftsberichte-download.de/2021/ENAG99.pdf</a>
Heidelberg Materials	<a href="https://www.heidelbergmaterials.com/de/nachhaltigkeitsbericht">https://www.heidelbergmaterials.com/de/nachhaltigkeitsbericht</a> ; <a href="https://www.heidelbergmaterials.com/de/geschäftsbericht-2021">https://www.heidelbergmaterials.com/de/geschäftsbericht-2021</a>
RWE	<a href="https://www.rwe.com/-/media/RWE/documents/05-investor-relations/finanzkalender-und-veroeffentlichungen/2021-GJ/2022-03-15-rwe-geschäftsbericht-2021.pdf?sc_lang=de-DE">https://www.rwe.com/-/media/RWE/documents/05-investor-relations/finanzkalender-und-veroeffentlichungen/2021-GJ/2022-03-15-rwe-geschäftsbericht-2021.pdf?sc_lang=de-DE</a>
Salzgitter	<a href="https://www.salzgitter-ag.com/fileadmin/finanzberichte/2021/gb2021/de/downloads/szag-gb2021-gesamt.pdf">https://www.salzgitter-ag.com/fileadmin/finanzberichte/2021/gb2021/de/downloads/szag-gb2021-gesamt.pdf</a> ; <a href="https://www.salzgitter-ag.com/fileadmin/reports/2021/nfr/de/downloads/szag-gesonderter-nichtfinanzieller-konzernbericht-2021.pdf">https://www.salzgitter-ag.com/fileadmin/reports/2021/nfr/de/downloads/szag-gesonderter-nichtfinanzieller-konzernbericht-2021.pdf</a>
SAP	<a href="https://www.sap.com/integrated-reports/2021/en.html?pdf-asset=903be721-1b7e-0010-bca6-c68f7e60039b&amp;page=2;">https://www.sap.com/integrated-reports/2021/en.html?pdf-asset=903be721-1b7e-0010-bca6-c68f7e60039b&amp;page=2;</a>
Siemens	<a href="https://assets.new.siemens.com/siemens/assets/api/uuid:9972c7d3-52bc-4498-b896-5cdea51a71fb/nachhaltigkeit2021-de.pdf">https://assets.new.siemens.com/siemens/assets/api/uuid:9972c7d3-52bc-4498-b896-5cdea51a71fb/nachhaltigkeit2021-de.pdf</a> ; <a href="https://new.siemens.com/content/dam/internet/siemens-com/global/company/investor-relations/application-pages/report/report4you_de/assets/pdfs/Siemens-Bericht_GJ2021.pdf">https://new.siemens.com/content/dam/internet/siemens-com/global/company/investor-relations/application-pages/report/report4you_de/assets/pdfs/Siemens-Bericht_GJ2021.pdf</a>
Thyssenkrupp	<a href="https://ucpcdn.thyssenkrupp.com/_binary/UCPthyssenkruppAG/a2b1a82f-76fd-4dc4-8a8a-6e202064cfb6/thyssenkrupp-GB-de-2020-2021-Web.pdf">https://ucpcdn.thyssenkrupp.com/_binary/UCPthyssenkruppAG/a2b1a82f-76fd-4dc4-8a8a-6e202064cfb6/thyssenkrupp-GB-de-2020-2021-Web.pdf</a> ; <a href="https://www.thyssenkrupp.com/de/unternehmen/nachhaltigkeit/umwelt/energie">https://www.thyssenkrupp.com/de/unternehmen/nachhaltigkeit/umwelt/energie</a>
Vattenfall	<a href="https://group.vattenfall.com/siteassets/corporate/investors/annual-reports/2021/vattenfall-annual-and-sustainability-report2021.pdf">https://group.vattenfall.com/siteassets/corporate/investors/annual-reports/2021/vattenfall-annual-and-sustainability-report2021.pdf</a>

## Appendix 5: Assumptions on Hedging Calculations

We assess hedging risks via a historical analysis of data from 2015 to 2022, using coherent historical data on renewable capacities, renewable time series and day-ahead price series (SMARD, 2023).

For each year, wholesale electricity costs, and (positive/negative) payments of all contracts (scaled to the concluded contract volume) in all quarter hours of the year are calculated. Contract payments critically depend on the contract (strike) price. Four contract types are modelled:

- RE-Pool
- Baseload (constant volume in all hours of the year)
- Peakload (constant volume in all peak hours (08:00-20:00))
- 4-h-Price-Spread, which for a flat payment, pays out the price spread between the 16 highest and 16 lowest quarter hours of a day

In all cases, in order to focus on the hedging aspect, we assume that modelled contracts (CfD, Baseload, Peakload, and 4-hour-Spread-hedge) have a fair strike price, i.e. over the period of 2015 to 2022 they are in expectation cost neutral, and only shift costs between years.

We refer to contract volumes as percent of demand, i.e. a 100% baseload contract hedges the same amount of energy over a period of one year, as is consumed. In general, the hedged hours will deviate from the hours where energy is consumed (depending on the demand profile). For the 4-h-Price-Spread, a 100% coverage is defined as hedging 4 hours flat demand per day.

For the RE-Pool we assume that, as described in the main text, it passes on the volume risks to consumers, delivers energy for a standardised weather year, i.e. if a consumer hedges 100% of their yearly demand, the CfD contract is going to hedge that yearly demand on average (with variations between the years). All other contract types deliver a fixed volume.

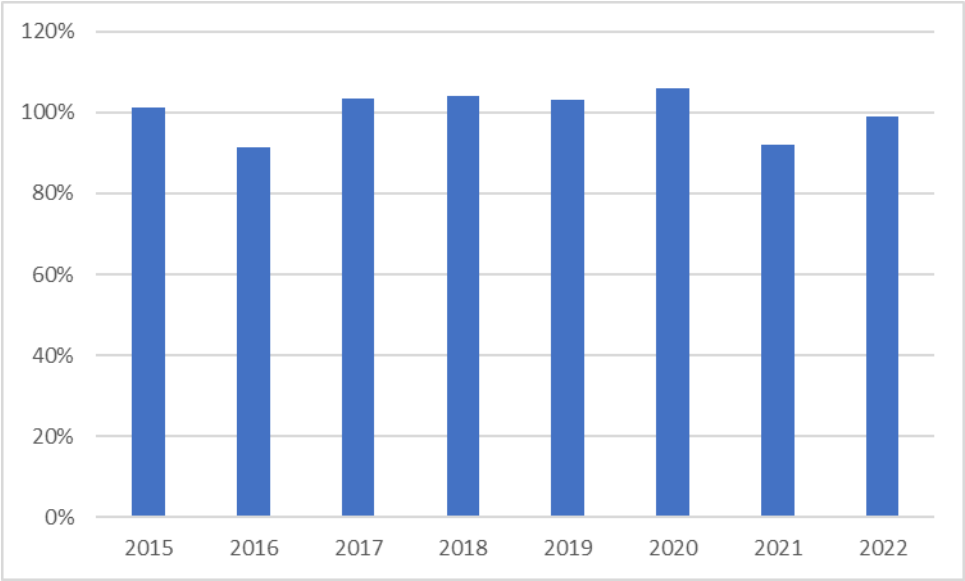


Figure 8 Volume of CfD contract in historical years

We investigate 4 scenarios:

1. A pure RE-Pool hedge (100%)
2. A pure baseload hedge (100%)
3. An RE-Pool hedge (100%) & a optimised 4-hour-price spread hedge
4. An optimised baseload and peak-load hedge

In scenarios 3 and 4, the optimal contractual volumes are determined separately for the three demand profiles (household, commercial and baseload). For the optimal-4-hour-price-spread the optimal volumes are:

- Baseload: 30%
- Commercial: 34.6%
- Household: 37.3%

For the baseload and peakload hedge the optimal volumes are:

- Baseload: 100% Baseload, 0% Peakload

- Commercial: 102.7% Baseload, 0% Peakload
- Household: 0% Baseload, 101% Peakload

As in recent years base- and peakload prices have been relatively close to each other, together with the epsilon of the applied solver corner solutions are identified.

To further investigate how the contract hedges in times of crisis, Figure 9 and 10 provides the monthly electricity expenditures in 2022 under a 100% RE-Pool with a 33% 4-hour-price-spread hedge) (Figure 9) and 100% baseload hedge (Figure 10), and compares it to the unhedged daily electricity prices and monthly costs (scaled to a yearly electricity consumption of 1 MWh). As can be seen the volatility is strongly reduced, but not completely removed.

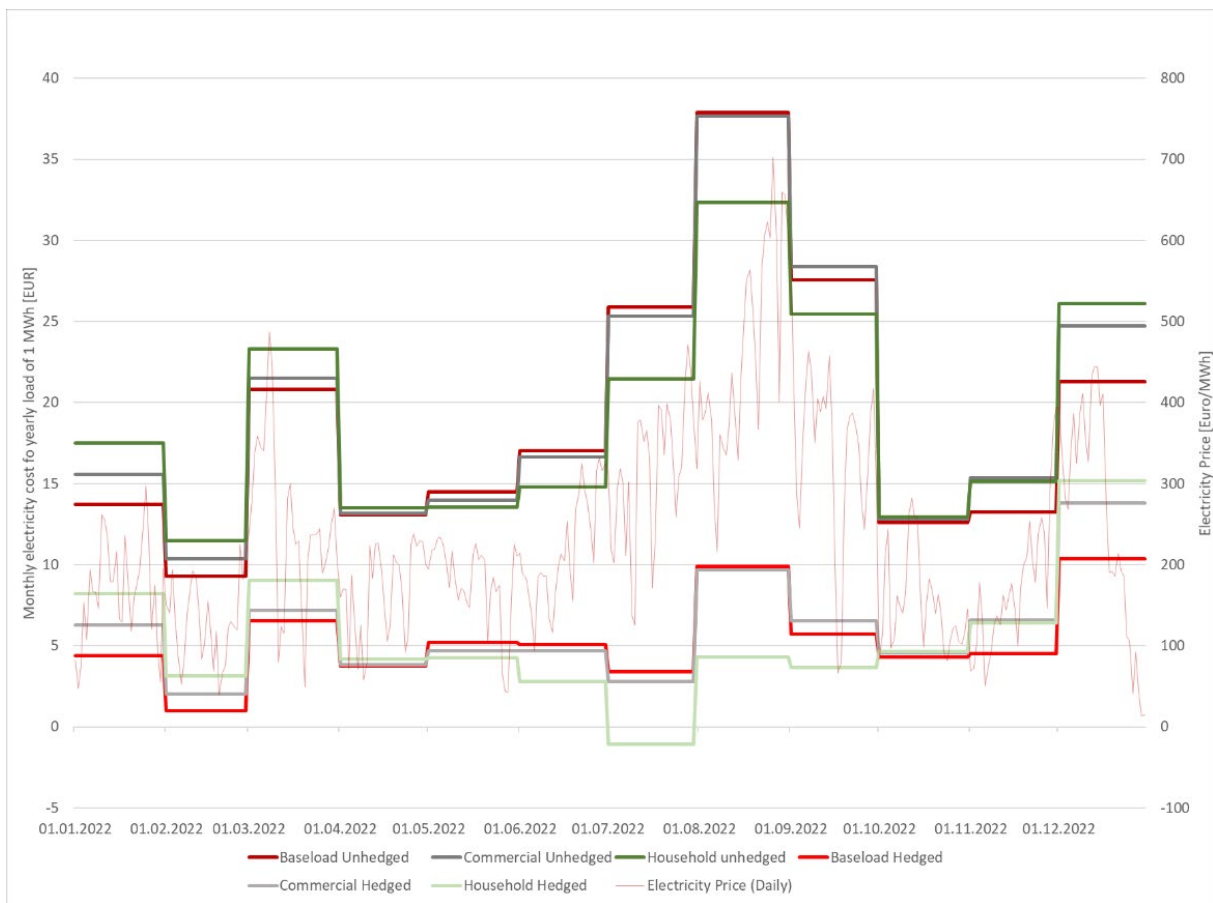


Figure 9 Monthly electricity costs (hedged with 100% RE-Poo and 33% 4-hour-price hedge & unhedged) for 1 MWh per year (left axis) and electricity prices (right axis)

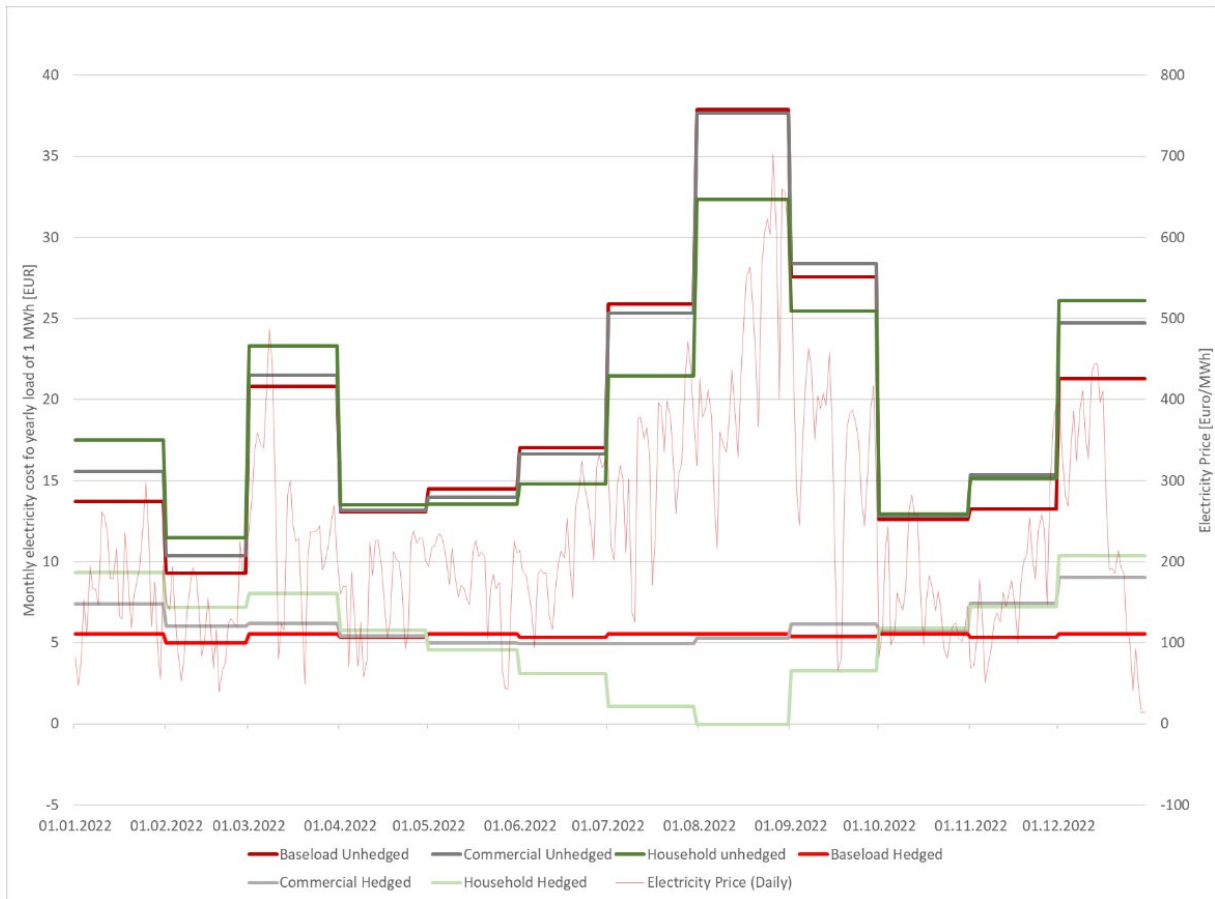


Figure 10 Monthly electricity costs (hedged with 100% Baseload & unhedged) for 1 MWh per year (left axis) and electricity prices (right axis)