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Hedging as a Match-Maker: Unlocking Industrial Demand Flexibility for Renewable Energy Integration

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In this paper we analyze the design of hedging products for electricity to unlock industrial investments into load shifting capacity. Currently, most industrial consumers buy a large share of electricity in advance on forward and future markets, where the most liquid products are baseload contracts (EEX, 2025). However, using these contracts severely limits the direct exposure to price signals on the spot market, which diminishes the incentives for load shifting (Lund et al., 2015; Mays, 2021). To successfully integrate the growing share of renewable energy generation, however, it is essential to unlock the large untapped potential of industrial load shifting capacity (Howard et al., 2021). An alternative product for hedging could be a renewable energy profile (REP) hedge, which guarantees a fixed price for the amount of electricity supplied that is proportional to the generation profile of renewable energies. Features of the REP hedge can already be found in existing contract structures. For example, in long-term pay-as-produced power purchasing agreements (PPA), the consumer guarantees to buy all or a share of the generation of a renewable energy plant at a fixed price. As the generation from a single RE plant can be quite volatile, Neuhoff et al. (2023) propose a renewable energy pool (RE pool), through which the consumers'electricity demand is hedged by a portfolio of RE plants. We show that a REP hedge can, compared to the current market structure, positively impact firms'incentives to undertake flexibility investments.

We build a two-stage analytical model of investment under uncertainty. In the first stage, a representative industrial firm can invest into flexible production capacities. In the second stage, the firm can utilize this flexibility in the production process to react to realized levels of renewable energy supply and resulting electricity prices via the adjustment of its production level (load shifting). We compare the investment outcomes depending on the electricity procurement strategy of the firm: it is either hedged with a conventional baseload product, the REP hedge, or not hedged at all, thus being fully exposed to spot market prices. We explicitly take into account the notion of risk-averse decision making via the application of the conditional value at risk (Rockafellar & Uryasev, 2000). The core insight of our model is that when comparing risk-averse firms, the REP hedge is more successful at incentivizing investment into flexibility than the status quo of a baseload hedge and pure spot market procurement. Investment of the risk-averse REP firm is under any model configuration at least as big as those of baseload and spot firms. Further, we find that risk-averse firms under the baseload hedge and spot market procurement invest less than their risk-neutral counterpart. This result is driven by the adjustment to low price volatility in the spot market which is decreasing the relative benefit of flexibility investments. Contrary to that, the risk-averse REP firm will invest more than its risk-neutral counterpart when high volatility is a cost driver. This is best responded to with high investment levels.

Within numerical simulations, we further investigate several variations to the analytical basemodel, such as effects of different compositions of the RE portfolio underlying the REP hedge and variations to the flexibility investment cost function. When cheap flexibility options are available, they are invested in regardless of the hedging design. However, in sectors in which flexibility is harder to unlock, incentives from the current hedging design are insufficient and only the REP hedge succeeds to unlock higher levels of flexibility investments. The REP hedge is thus a promising alternative to prevalent hedging instruments for fostering the development of flexibility.

We contribute to the literature in three ways: Firstly, to the best of our knowledge, we are the first to provide a detailed analysis of the potential of a REP hedge for unlocking flexibility. By that, we contribute to a literature of how electricity market design impacts incentives for demand side flexibility, necessary for the integration of intermittent renewable energies. Secondly, by building a model of flexibility investments under uncertainty, we expand the literature of flexibility investments which has mostly focused on implications for the supply side and its investments into generation capacity (Diaz et al., 2019; Möbius et al., 2023). Thirdly, those papers that do look at demand side investments mostly neglect the effect of risk aversion on such investments (e.g. Ambrosius et al., 2018). Hence, our core contribution is the analytical discussion of a hedge based on the renewable energy profile in the context of demand-sided investments into flexibilization, while accounting for risk aversion.

Our results show the potential of a REP hedge to unlock industrial flexibility potential. Regardless of this, such profile hedging has not yet been able to establish itself successfully on the futures market. To already jumpstart the usage of a REP hedge now, government support policies could be linked to it. An example in which this is already partially implemented are carbon contracts for difference (CCfDs) in Germany. They de-risk industrial investments into climate friendly production technologies by covering investment and operational cost differences relative to the conventional production method. Hereby, the operational cost component is designed as a composition of a baseload and REP hedge. Our model can be used to reveal the required balance of the two hedges needed to have a positive impact on flexibility investments.

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