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Potential benefits of optimal intra-day electricity hedging for the environment : the perspective of electricity retailers

Raphaël BOROUMAND [*], Stéphane GOUTTE [†] and Thomas PORCHER [*].

April 30, 2019

Abstract

Our article provides a better understanding of risk management strategies for all energy market stakeholders. A good knowledge of optimal risk hedging strategies is not only important for energy companies but also for regulators and policy makers in a context of climate emergency. Indeed, the electricity sector is key to achieve energy and ecological transition. Electricity companies should be on frontline of climate change struggle. Taking the perspective of electricity retailers, we analyze a range of portfolios made of forward contracts and/or power plants for specific hourly clusters based on electricity market data from the integrated German-Austrian spot market. We prove that intra-day hedging with forward contracts is sub-optimal compared to financial options and physical assets. By demonstrating the contribution of intra-day hedging with options and physical assets, we highlight the specificities of electricity markets as hourly markets with strong volatility during peak hours. By simulating optimal hedging strategies, our article proposes a range of new portfolios for electricity retailers to manage their risks and reduce their sourcing costs. A lower hedging cost enables to allocate more resources to digitalization and energy efficiency services to take into account customers' expectations for more climate-friendly retailers. This is a virtuous circle. Retailers provide high value-added energy efficiency services so that consumers consume less. The latter contributes to reach electricity reduction targets to fight climate warming.

Keywords: : Diversification; Climate; Electricity; Risk; Intra-day; Hedging.

JEL classification: C02, L94, G11, G32.

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1 Introduction and literature review

In liberalized wholesale and retail electricity markets, electricity suppliers source electricity through long-term contracts, on the spot market, or by self-generating for(re)sale on the retail market. In the residential sector, suppliers must serve fluctuating loads at prices that are usually fixed, and given their 'obligation to serve', they cannot curtail delivery (Boroumand and Zachmann, 2012; Bushnell et al., 2008). As market intermediaries, electricity suppliers have the contractual obligation to balance their procurement and sales portfolios without the lever of storage (Boroumand, 2015). The economic non-storability of (large) electricity volumes contributes to making electricity market intermediation very specific. This limited ability to store electricity, combined with stochastic demand, explains the extreme and notably high volatility of electricity spot prices, which are characterized by frequent spikes. Moreover, the continuing development of intermittent solar and wind capacities increases the need to mitigate hazards on the offer side due to climatic variations. In summary, the hourly variability in demand, the short-term inelasticity of that demand, and the rigidity of supply expose suppliers' net profits to hourly volumetric and price risks, both of which are correlated with weather conditions. A supplier's profit, facing a multiplicative risk of price and quantity, is nonlinear in price. Hedging should be against variations in total costs, which is complex within hourly markets. Consequently, suppliers need to engage in risk management strategies on an intra-day basis given the significantly superior efficiency of intra-day hedging over daily (and therefore weekly, monthly and yearly) hedging (Boroumand et al, 2015). As a consequence of electricity liberalization, a wide variety of hedging instruments have emerged (Geman, 2008; Hull, 2005; Hunt, 2002). Several articles have analyzed hedging in electricity markets (Chemla et al, 2011; Oum et al, 2010; Jun et al, 2006; Oum et al, 2006). Our article demonstrates, through the Var(95%)and the corresponding CVar, that hedging through forwards [or futures] is sub-optimal, regardless of the hour of the day, and that financial options or physical assets are systematically required. Morrover, the issues and the measure of flexibility in a RES increasing production appears crucial. Recently, Goutte and Vassilopoulos 2018, quantified the value of a flexible resource on the wholesale power market. They shown that flexibility can be decomposed in two components: immediacy value and ramping capability. They modelled and quantified this value of the flexibility component on auction prices.

A good knowledge of optimal risk hedging strategies is so not only important for energy companies but also for regulators and policy makers in a context of climate emergency. Indeed, the electricity sector is key to achieve energy and ecological transition. Electricity companies should be on frontline of climate change struggle. Taking the perspective of electricity retailers, we analyze a range of portfolios made of forward contracts and/or power plants for specific hourly clusters based on electricity market data from the integrated German-Austrian spot market. We prove that intra-day hedging with forward contracts is sub-optimal compared to financial options and physical assets.

By demonstrating the contribution of intra-day hedging with options and physical assets, we highlight the specificities of electricity markets as hourly markets with strong volatility during peak hours.

By simulating optimal hedging strategies, our article proposes a range of new portfolios for electricity retailers to manage their risks and reduce their sourcing costs. A lower hedging cost enables to allocate more resources to digitalization and energy efficiency services to take into account customers' expectations for more climate-friendly retailers. This is a virtuous circle. Retailers provide high value-added energy efficiency services so that consumers consume less. The latter contributes to reach electricity reduction targets to fight climate warming.

The article is structured as follows. Section 2 is a devoted to the data and its statistical properties. Section 3 describes our methodology. Section 4 presents our results of intra-day optimized hedging portfolios. The last section concludes and provides policy recommendations to argue in term of environmental issues and perspective of electricity retailers.

2 Data

2.1 The German-Austrian market, a relevant case study

The study of the German-Austrian market is relevant for several reasons. First, the spot price is the reference price of the German market. The German spot market is large, with a low HHI index and a high liquidity. It has the capacity to absorb large volumes of electricity from renewable sources and therefore plays a key role in the German energy transition. The trading volumes on the spot power market increased by 4% from 2014 to 2015, with a total of 302 TWh. During the same period, the day-ahead market grew faster from (26.4 TWh to 37.5 TWh) than the Day-Ahead market, and it remains one of the biggest and most liquid day-ahead hubs in Europe.

On the German market, there were more than 75 GW of installed solar PV or wind capacity in 2015. The hourly variability of load, intermittent renewable generation and price justifies an intra-day hedging approach. Intermittent producing capacities require significant trading capabilities to harmonize upstream and downstream portfolios.

2.2 Electricity loads and spot prices

To calculate the loss of each portfolio, we realize simulations with hourly price and volume data from EPEX SPOT. We examine the German-Austrian hourly prices and volumes from January 1st 2013 to September 13th 2015. We realize simulations for four clusters hours (9 am, 12 pm, 6 pm, 9 pm) based on two risk indicators (VaR and CVaR) (definitions and details about these two risk indicators are given in Section 3).

We model the portfolio risk calculation as the expected maximum loss. Figures 1 and 2 aim at describing statistically our data to show the specificity of each cluster in terms of electricity load and price. Each cluster represents a group of hours with homogeneous statistical features. The specific statistical features of each cluster justifies our methodological approach of intraday periodicity.

Figure 1: Spot electricity prices for each cluster hour from 01 Jan 2013 to 13 Sep 2015. (top left 9 am, top right 12 pm, bottom left 6 pm and bottom right 9 pm)

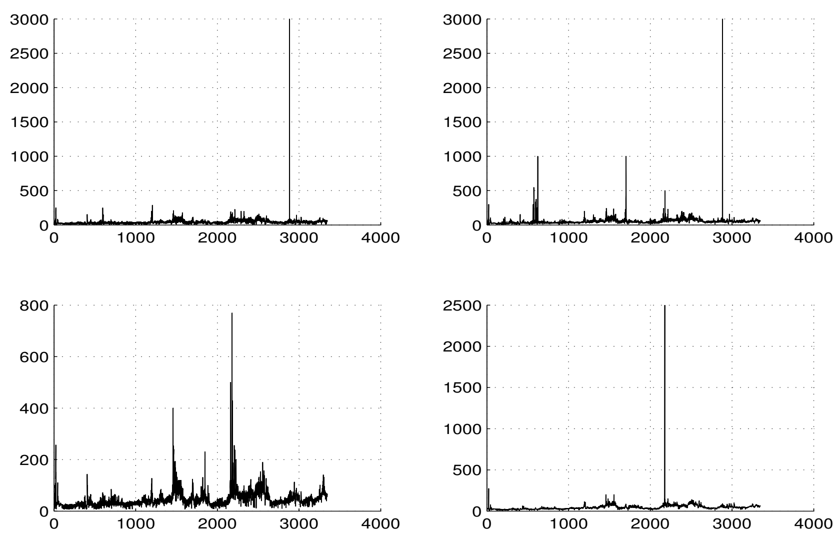
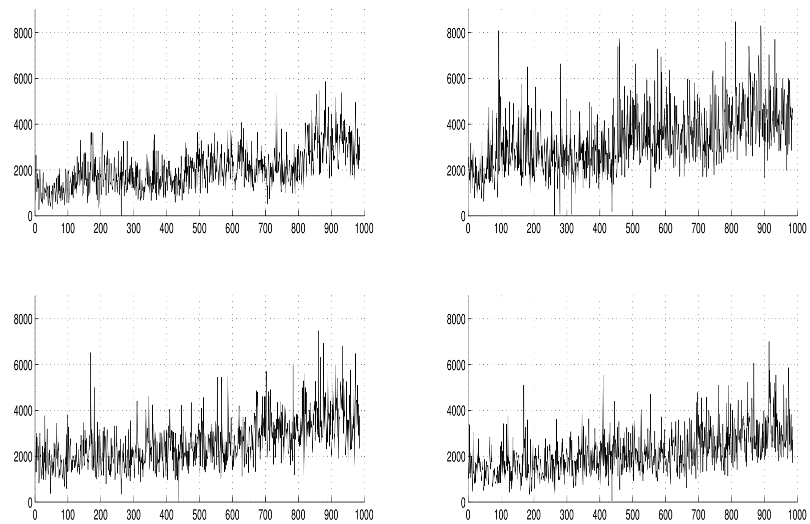


Figure 1 clearly exhibits spot price spikes which appear at different time with respect to the cluster hour. Moreover, we see too that volatilities are very different. Figure 2 shows the different levels of consumption volumes for each cluster hour.

The hourly variability in load and price justifies an intra-day hedging approach that takes into account the specific statistical features of each cluster hour subsequent to the

Figure 2: Electricity load for each cluster hour from 01 Jan 2013 to 13 Sep 2015. (top left 9 am, top right 12 pm, bottom left 6 pm and bottom right 9 pm)



variability of offer and demand.

3 Methodology

In this paper, we compare the risk profiles of a range of intra-day hedging portfolios.

For this purpose, we compare the risk profiles of different hedging portfolios with the traditional Value at Risk (VaR) indicator. The Value at Risk (VaR) is an aggregated measure of the total risk of a portfolio of contracts and assets. The VaR summarizes the expected maximum loss (worst loss) of a portfolio over a target horizon (10 years in this article) within a given confidence interval (generally 95%). Thus, VaR is measured in monetary units; in our article, these units are Euros. As the maximum loss of a portfolio, the VaR(95%) is a negative number. Therefore, maximizing the VaR is equivalent to minimizing the portfolio's loss. We rely on the Value-at-Risk because it is a good measure of the downside risk of a portfolio and is, for example, used as the preferred criterion for market risk in the Basel II agreement. We strengthen the robustness of our results with the CVaR.

The Conditional Value-at-Risk, CVaR, is strongly linked to the previous risk measure (i.e., VaR) which is, as mentioned above, the most widely used risk measure in the practice of risk management. By definition, the VaR at level $\alpha \in (0, 1)$, $VaR(\alpha)$ of a given portfolio loss distribution, is the lowest amount not exceeded by the loss with probability α (usually $\alpha \in [0.95, 1)$). The Conditional Value at Risk at level α $CVaR(\alpha)$ is the conditional expectation of the portfolio losses beyond the $VaR(\alpha)$ level. Compared to VaR, the CVaR is known to have better mathematical properties and accounts for the possible heavy tails of portfolio loss distribution.

3.1 Payoff of the assets and contracts within a hedging portfolio

A supplier is assumed to have concluded a retail contract (the retail contract is given ex ante and is therefore not a portfolio's parameter of choice) with its customers, and that contract implies stochastic demand V_t for $t = 1 : T$. The demand distribution is known to the supplier, and the uncertainty about the actual demand V_t is completely resolved in time t. To fulfill its retail commitments, the supplier can buy electricity on the spot market at the ex ante uncertain spot market price P_t. The spot market price distribution is known by the supplier. To reduce its risk from buying an uncertain amount of electricity at an uncertain price, the supplier can rely on forward contracts or options, and/or it can also acquire power plants. All contracts (including the retail contract and the physical assets' generation volumes) are settled on the spot market that is assumed to be perfectly liquid.

We now present the structures of our portfolios. Let us denote by $\pi_{i,t}$, the price at time $t = 1 : T$ of a particular contract with name i. We consider five different contracts/assets – namely a retail contract, a forward contract, a power plant, a call option and a put option. Contrary to forwards, options replicate the operational flexibility of physical assets. Forward would be efficient if demand were constant and not correlated to the spot price. We recall the payoff of these five contracts/assets given the spot price P_t.

Retail contract:

$$\pi_{retail,t} = -P_t.V_t + \mathbb{E}[P_t.V_t]$$

Forward:

$$\pi_{forward,t} = V_{forward}.P_t - \mathbb{E}[V_{forward}.P_t]$$

Power plant:

$$\pi_{plant,t} = V_{plant} \times \max\left(P_t - mc, 0\right) - \mathbb{E}\left[V_{plant} \times \max\left(P_t - mc, 0\right)\right]$$

Call option:

$$\pi_{call,t} = V_{call} \times \max\left(P_t - K, 0\right) - \mathbb{E}\left[V_{call} \times \max\left(P_t - K, 0\right)\right]$$

Put option:

$$\pi_{put,t} = V_{put} \times \max\left(K - P_t, 0\right) - \mathbb{E}\left[V_{put} \times \max\left(K - P_t, 0\right)\right]$$

If for example, the electricity spot price (P_t) is above the strike price of the options (K), there is a positive payoff of the call option, while the payoff of the put option is zero. The payoff of the power plant depends on the installed capacity of the plant (V_{plant}) and its marginal cost (mc), and only the payoff of the retail contract depends on the stochastic demand V_t. We subtract the expected value $\mathbb{E}(.)$ from the gross payoff of all contracts/assets to obtain a zero expected value. That is, we assume that we are in a perfect and complete market. Consequently, arbitrage would not allow the existence of systematic profits.

3.2 Risk minimization

To simulate the payoffs some assumptions on the distribution of the electricity spot price and retail volume have to be made. We rely on real data on German-Austrian hourly prices and volumes from January 1st 2013 to September 13th 2015. It corresponds to 23664 observations (i.e. 986 values for each hours of 24h day.) The hourly prices and the corresponding loads are obtained from EPEX SPOT SE[1] (the European Power Exchange). To obtain realistic simulations we sort the observed price-load combinations by load. Then, the central points (medians) of 2000 windows of $\frac{986}{2} = 493$ neighbouring observations are drawn from a truncated normal distribution. The mean of this distribution is 493, representing the central point of the 2.7 years data. The variance of the central points is 493/4).

The distribution is truncated below 986/2 and above 98686/2 to fit the data sample. Note that, due to the normal distribution, windows with a median load closer to that of the observed sample are more likely than windows with a median very different from that of the real data. Finally, from each of the 2000 windows we draw randomly with replacement 986 hourly price-load combinations. Consequently, in expectation the median of the observed data (load) is equal to that of the simulated data. Despite of the non-normal (joint) distribution of the observed data, the mean of the simulated load is slightly close to the observed loads. The mean price of the simulated data is also close than the observed data for each cluster hours.

Table 1: Descriptive Statistics of the simulated data with respect to real estimated data.

	9am		**12pm**	
	Real data	Simulated data	Real data	Simulated data
Mean price ($\mathbb{E}[P_t]$)	30.86	30.86	32.56	34.17
Median price (mc)	28.45	28.81	26.26	26.49
Mean load	2020.49	1921.89	352.18	306.19
Median load	402.04	375.72	289.00	289.00
Variance price	402.04	375.71	642.16	788.88
Variance load	788026.72	201202.80	80762.55	15959.18
	6pm		**9pm**	
	Real data	Simulated data	Real data	Simulated data
Mean price ($\mathbb{E}[P_t]$)	29.81	29.63	26.13	26.09
Median price (mc)	26.10	26.10	25.13	25.03
Mean load	2588.96	2486.51	2144.27	2037.87
Median load	2461.35	2459.70	2008.80	2008.40
Variance price	291.58	246.15	130.36	165.32
Variance load	1079193.92	263287.32	889971.84	212472.56

The marginal generation cost of the power plant is set to the median of the simulated

[1]It is an exchange for power spot trading in Germany, France, the United Kingdom, the Netherlands, Belgium, Austria, Switzerland and Luxembourg.

spot prices mc Euro/MWh (second line of Table 1), thus representing a peak load power plant. The strike price of the options is set to the expectation value of the spot price $K = \mathbb{E}[P_t]$ Euro/MWh (first line of Table 1).

We clearly see in Table 1 that all of the statistical indicators vary considerably, depending on the choice of spot hour prices. For instance, the variance price for the 9 am cluster is 375.72 whereas it is only 165.32 for the 9 pm cluster. This is related to the fact that electricity markets are hourly markets. The hourly variability of price and load justify an intra-day hedging position rather than a daily one.

We can calculate the cumulated annual payoffs of the N=23664 hourly price/volume combinations for all 2000 simulations given the portfolio $(V_{forward}, V_{plant}, V_{call}, V_{put})$:

$$\begin{aligned} \pi^i \;=\; & \sum_{t=1}^{N} \left[\pi_{retail,t}(P_t^i, V_t^i)\right] + \left[V_{forward} \times \pi_{forward,t}(P_t^i)\right] \\ & + \left[V_{plant} \times \pi_{plant,t}(P_t^i, mc)\right] + \left[V_{call} \times \pi_{call,t}(P_t^i, K)\right] \\ & + \left[V_{put} \times \pi_{put,t}(P_t^i, K)\right] \end{aligned} \tag{3.1}$$

Thus, π^i is the global payoff of the ith hourly price and volume simulation of a day given the portfolio defined by $(V_{forward}, V_{plant}, V_{call}, V_{put})$. Using an optimization routine, the portfolio that produces the lowest VaR(95%) and CVaR can be identified.

The objective is to identify the portfolio consisting of one 1 MWh baseload retail contract and a linear combination of financial contracts and physical assets that reduces the supplier's risk. Thus, the factors for the other contracts/assets are also measured in MWh.

4 Intra-day optimized portfolios

Our global objective is to test various portfolios structures on an intra day timeframe. We present 9 hedging scenarios. Therefore, some portfolios might be more or less efficient regarding a given cluster hour. We present the payoff of each contract within our portfolios. Portfolio 1 combines forwards, call option, put option, and powerplants. It is the most complete intra day portfolio. The purpose is to evaluate the contribution and potential complementarity of a large variety of hedging devices as measured by VaR (95%) and CVaR (95%). Portfolio 2 is without options. Portfolio 3 is only options. The objective is to test the efficiency of options to see if they are necessary and/or sufficient as substitutes of physical plants. Portfolio 4 is only forwards. We test if forwards could be efficient at least for some clusters. Portfolio 5 is only powerplant. Our objective is to see if upstream vertical integration is required for all cluster hours. For portfolios 6 to 9, we test the contribution of various producing technologies to the risk profile of each cluster hour. By analyzing intra-day portfolios, our purpose is to examine the impact of baseload, semi-peak, and peak load plants given electricity load and price statistical features per cluster hour. Portfolio 7 contains three producing technologies. We want to check if the complementarity of the three technologies in terms of cost and return has a positive impact in terms of hedging. Portfolio 8 contains only baseload and peak load powerplants. Portfolio 9 contains a forward and a peak load plant. The idea is to see whether this combination is a good hedge for some clusters so that there is no need to invest on other producing technologies.

4.1 Optimal hedging portfolio for each cluster hour in a standard case

The following Tables give the results for two types of portfolios that maximize the VaR(95%) and CVaR.

Table 2: Portfolios that maximize the VaR(95%) and CVaR for the 9 am cluster hour.

Portfolios containing one retail contract							
#	Used assets	$V_{forward}$	$V_{plant,50}$	V_{call}	V_{put}	$VaR(95\%)$	$CVaR(95\%)$
1	**All possible contracts**	-1,05	0,78	1,32	-1,68	**-280,06**	**-366,42**
2	Without options	0,63	0,46	0,00	0,00	-280,38	-367,00
3	Only Options	0,00	0,00	1,10	-0,64	-281,31	-368,72
4	Only forward	0,80	0,00	0,00	0,00	-345,47	-430,71
5	Only power plant	0,00	1,08	0,00	0,00	-569,60	-721,24
Portfolios containing one retail contract and different producing technologies							
#	Used assets	$V_{forward}$	$V_{plant,50}$	$V_{plant,25}$	$V_{plant,75}$	$VaR(95\%)$	$CVaR(95\%)$
6	Forward and 3 plants	0,59	0,03	0,39	0,00	-282,83	-393,50
7	3 plants	0,00	0,00	1,10	0,00	-387,02	-493,75
8	$V_{plant,25}$ and $V_{plant,75}$	0,00	0,00	1,10	0,00	-387,02	-493,75
9	Forward and $V_{plant,75}$	0,73	0,00	0,00	0,41	-290,65	-377,19

Table 3: Portfolios that maximize the VaR(95%) and CVaR for the 12pm cluster hour.

Portfolios containing one retail contract							
#	Used assets	$V_{forward}$	$V_{plant,50}$	V_{call}	V_{put}	$VaR(95\%)$	$CVaR(95\%)$
1	**All possible contracts**	0,70	1,93	-1,71	-0,03	**-261,88**	**- 496,66**
2	Without options	0,88	0,29	0,00	0,00	-285,93	-500,13
3	Only Options	0,00	0,00	1,09	-1,01	-295,51	-545,66
4	Only forward	1,07	0,00	0,00	0,00	-308,44	-550,96
5	Only power plant	0,00	1,32	0,00	0,00	-435,71	-607,05
Portfolios containing one retail contract and different producing technologies							
#	Used assets	$V_{forward}$	$V_{plant,50}$	$V_{plant,25}$	$V_{plant,75}$	$VaR(95\%)$	$CVaR(95\%)$
6	Forward and 3 plants	0,87	0,22	0,08	0,00	-284,62	-497,39
7	3 plants	0,00	0,00	1,11	0,00	-364,92	-571,46
8	$V_{plant,25}$ and $V_{plant,75}$	0,00	0,00	1,11	0,00	-364,92	-571,46
9	Forward and $V_{plant,75}$	1,05	0,00	0,00	0,05	-304,98	-553,91

Table 4: Portfolios that maximize the VaR(95%) and CVaR for the 6pm cluster hour.

	Portfolios containing one retail contract						
#	Used assets	$V_{forward}$	$V_{plant,50}$	V_{call}	V_{put}	$VaR(95\%)$	$CVaR(95\%)$
1	All possible contracts	0,00	0,00	1,04	-0,86	-275,54	-372,88
2	Without options	0,84	0,20	0,00	0,00	-282,66	-380,46
3	**Only Options**	0,00	0,00	1,04	-0,86	-275,54	**-362,08**
4	Only forward	0,83	0,00	0,00	0,00	-284,57	-362,67
5	Only power plant	0,00	1,09	0,00	0,00	-444,19	-559,78
	Portfolios containing one retail contract and different producing technologies						
#	Used assets	$V_{forward}$	$V_{plant,50}$	$V_{plant,25}$	$V_{plant,75}$	$VaR(95\%)$	$CVaR(95\%)$
6	**Forward and 3 plants**	0,89	0,01	0,01	0,17	**-273,48**	-368,37
7	3 plants	0,00	0,00	0,99	0,04	-364,92	-459,00
8	$V_{plant,25}$ and $V_{plant,75}$	0,00	0,00	0,99	0,04	-364,93	-459,05
9	Forward and $V_{plant,75}$	0,90	0,00	0,00	0,18	-275,12	-367,81

Table 5: Portfolios that maximize the VaR(95%) and CVaR for the 9pm cluster hour.

	Portfolios containing one retail contract						
#	Used assets	$V_{forward}$	$V_{plant,50}$	V_{call}	V_{put}	$VaR(95\%)$	$CVaR(95\%)$
1	All possible contracts	3,14	0,02	-2,13	2,27	-169,17	-230,18
2	Without options	0,87	0,14	0,00	0,00	-170,66	-229,15
3	**Only Options**	0,00	0,00	0,89	-0,91	-169,49	**-217,70**
4	Only forward	0,89	0,00	0,00	0,00	-170,48	-219,58
5	Only power plant	0,00	1,19	0,00	0,00	-297,71	-389,24
	Portfolios containing one retail contract and different producing technologies						
#	Used assets	$V_{forward}$	$V_{plant,50}$	$V_{plant,25}$	$V_{plant,75}$	$VaR(95\%)$	$CVaR(95\%)$
6	**Forward and 3 plants**	0,87	0,00	0,00	0,14	**-168,04**	-222,13
7	3 plants	0,00	0,03	0,86	0,06	-249,35	-325,47
8	$V_{plant,25}$ and $V_{plant,75}$	0,00	0,00	0,88	0,10	-252,86	-324,32
9	Forward and $V_{plant,75}$	0,87	0,00	0,00	0,20	-168,59	-224,36

Tables 2 to 5 give the portfolios that maximize the VaR(95%) and CVaR for each cluster hour. We recall that the objective is to identify the portfolio consisting of one 1 MWh base load retail contract and a linear combination of financial contracts and physical assets that reduces the retailer's risk. Thus, if the retailer sells five retail contracts and would like to hedge this deal with only forward contracts (portfolio 4 in Table 2), he would have to buy $5 \times 0,80 = 4,00$ MWh forwards. In the same way, if he would like to hedge this deal with only options (portfolio 3 in Table 2), he would have to buy $5 \times 1,10 = 5,50$ MWh on a call option and sell $5 \times 0,64 = 3,20$ MWh on a put option. Any imbalance between the electricity sold and purchased (or produced) is settled directly in the spot market. It is not necessary to have equality between the quantities sold downstream and upstream. The volume of power plant contracts is constrained to be positive, whereas call option, put option and forward contracts can be both bought and sold on the market (i.e., negative quantities are allowed). If we consider the results obtained for the morning cluster (i.e., 9 am), the optimal hedging portfolio is given by 'All possible contracts'. This means that if all assets are allowed, this hedging portfolio produces a VaR(95%) of -280,06 and a CVaR of -366,42. This hedging portfolio consists of selling 1,05 MWh of forward, generating 0,78 MWh with the plant, buying 1.32 MWh on a call option, and selling 1,68 MWh with a put option.

With a hedging portfolio that does not include plants or forwards, a VaR(95%) very close to the unconstrained optimal portfolio (i.e., 'All possible contracts') can be reached if options are allowed (i.e., the hedging portfolio 'Only Options'), -281,31 against -280,06. This hedging portfolio consists of only buying 1,10 MWh on a call option and selling 0,64 MWh with a put option. If options cannot be chosen, the risk management characteristics of the 'Only Options' hedging portfolio can be reproduced with the hedging portfolio 'Without options' if power plants and forward contracts are allowed (-280,38 against -281,31). With the hedging portfolio 'Only forward' allowed, the VaR(95%) is 23% bigger than if both power plants and forward contracts are available portfolio choices (i.e., 'Without options'), -345,47 against -280,38 . Consequently, if options are not available to retailers (because, for example, no agent is willing to sell them as a counterparty), then power plants whose payoffs feature option-like characteristics will help the supplier to reduce its risk exposure.

Let us now consider portfolios that contain different types of power plants. In other words, power plants with different marginal costs are now included in the possible hedging portfolios. We introduce a low-cost technology, with the marginal cost being equal to the 25% percentile of the electricity price, and a high-cost technology, with the marginal cost being equal to the 75% percentile. We observe that the VaR(95%) can be further reduced. The optimal hedging portfolio ('Forward and 3 plants', see second part of Table 2) that consists of 0,03 MWh of the semi-peak power plant, 0,39 MWh of the baseload power plant, 0,00 MWh of the peak power plant and 0,59 MWh bought with a forward contract can reduce the VaR(95%) to -282,83. This implies a slight improvement with respect to the hedging portfolio for the semi-peak power plant and the forward contract (i.e., portfolio ‘Without options’), for which we obtain a VaR(95%)=280,38. Moreover, by allowing only power plants, it can be demonstrated that adding a power plant with different payoff characteristics might reduce the VaR(95%) of the portfolio. Going, for example, from the hedging portfolio $V_{plant,25}$ and $V_{plant,75}$ with a VaR(95%)= -387,02 or the hedging portfolio ‘Only power plant’ (which means only semi-peak power plant $V_{plant,50}$) with a VaR(95%)=-569,60 to the hedging portfolio with all three power plant types (i.e., ‘3 plants’) with a VaR(95%)=-387,02 reduces the VaR(95%) up to 47%.

Table 6: Optimal hedging portfolio for each cluster hour. The values of the corresponding VaR and CVaR are also given.

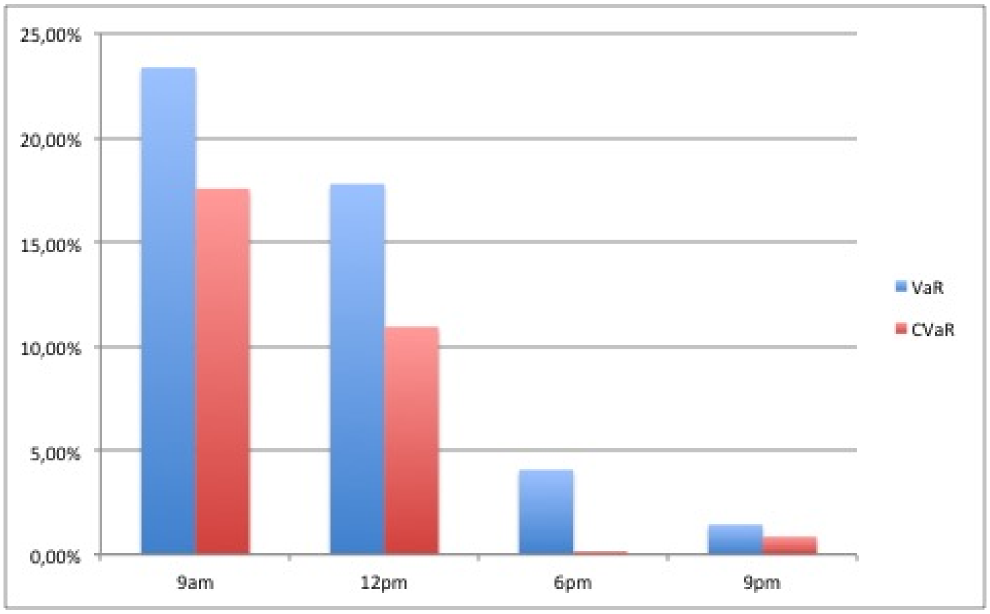
	VaR		**CVaR**	
Hour	Optimal Hedging Portfolio	Value	Optimal Hedging Portfolio	Value
9am	All possible contracts	-280,06	All possible contracts	-366,42
12pm	All possible contracts	-261,88	All possible contracts	-496,66
6pm	Forward and 3 plants	-273,48	Only Options	-362,08
9pm	Forward and 3 plants	-168,04	Only Options	-217,70

As shown by Tables 2 to 6, the simulations show that the optimal hedging varies considerably for each cluster. The variation in the optimal hedging strategy is not only in terms of VaR or CVaR values (i.e., we obtain results in the range of $-280,06$ to $-168,04$ for the VaR and $-496,66$ to $-217,70$ for the CVaR) but also in terms of the hedging portfolio. The optimal portfolios always include power plants or options. For all cluster-hours, the "only forward" portfolio is inefficient according to both risk indicators. These financial derivatives are structurally sub-optimal given the radical uncertainty of electricity markets. Indeed, efficient intra-day risk management should be against variations in total cost. A supplier's hourly profit is nonlinear in price given its exposure to the multiplicative risk of price and quantity. Consequently, hedging with linear payoff instruments (forwards or futures contracts) is not efficient within markets wherein the hourly stochastic demand is correlated to the spot price. Conversely, options and physical plants offer the operational flexibility required by electricity markets. Moreover, the complementarity and the non-correlation between the payoffs and risk profiles of 3 different power plants (baseload, semi-peak and peak) offer even more flexibility for relying on the 'best asset', depending on the hourly load profile.

Table 7: Increasing differential loss between the single forward hedging portfolio and optimal hedging given in Table 6.

Hour	Increasing loss in percentage	
	VaR	CVaR
9am	23,36%	17,55%
12pm	17,78%	10,93%
6pm	4,06%	0,16%
9pm	1,45%	0,86%

Figure 3: Increasing differential loss between the single forward hedging portfolio and optimal hedging given in Table 6.



We clearly see on Table 7 and corresponding Figure 3, that the retailer can have an increasing of his income using the optimal hedging obtained by our optimization and given in Table 6. Indeed, we can see that using for the cluster hour 9am the optimal strategy instead of the "single forward hedging portfolio" gives an increasing of income of 23.36% for the VaR and 17.55% for the CVaR.

The 'Only forward' portfolio is not efficient for the 9 am and 12 pm clusters but is efficient for the 6 pm and 9 pm clusters. This result can be explained by the 9 am cluster having the lowest variance compared to the 9 pm cluster (307.8 and 109.4, respectively, as shown by Table 1). As the evening clusters have the lowest variance, this enables efficient hedging with linear contracts such as forwards and futures, given the more predictable demand. In such cases, suppliers hedge the expected demand with the fixed quantity of the forward contract. Physical assets are so needed because no financial asset can offer the operational flexibility of physical assets in a market with radical uncertainty (stochastic demand combined with price volatility). Options are efficient because they offer the same flexibility as physical assets with a similar payoff structure that mirrors the payoff of a retail contract.

4.2 Correlation between the hedging portfolio for each cluster hour and the retail contract

The following Tables, 8 to 11 and Figure 4 present the characteristics of the different payoffs of the considered assets and their correlations with retail.

Table 8: Characteristics of the payoffs of the considered assets and correlation with retail for the 9 am cluster hour.

	Variance	VaR(95%)	Correlation with retail
Retail contract without hedge	423675,97	-1031,09	1,00
$V_{forward}$	432669,47	-1110,27	-0,93
$V_{plant,25}$	282709,58	-902,53	-0,93
$V_{plant,50}$	223459,53	-829,89	-0,85
$V_{plant,75}$	121434,93	-617,50	-0,76
V_{call}	213367,33	-804,16	-0,84
V_{put}	201162,97	-651,38	0,50

Table 9: Characteristics of the payoffs of the considered assets and correlation with retail for the 12 pm cluster hour.

	Variance	VaR(95%)	Correlation with retail
Retail contract without hedge	341888,40	-923,46	1,00
$V_{forward}$	282207,12	-833,81	-0,95
$V_{plant,25}$	200415,96	-715,14	-0,92
$V_{plant,50}$	152878,72	-615,38	-0,88
$V_{plant,75}$	63643,52	-402,37	-0,72
V_{call}	128305,94	-577,89	-0,86
V_{put}	77135,86	-449,27	0,70

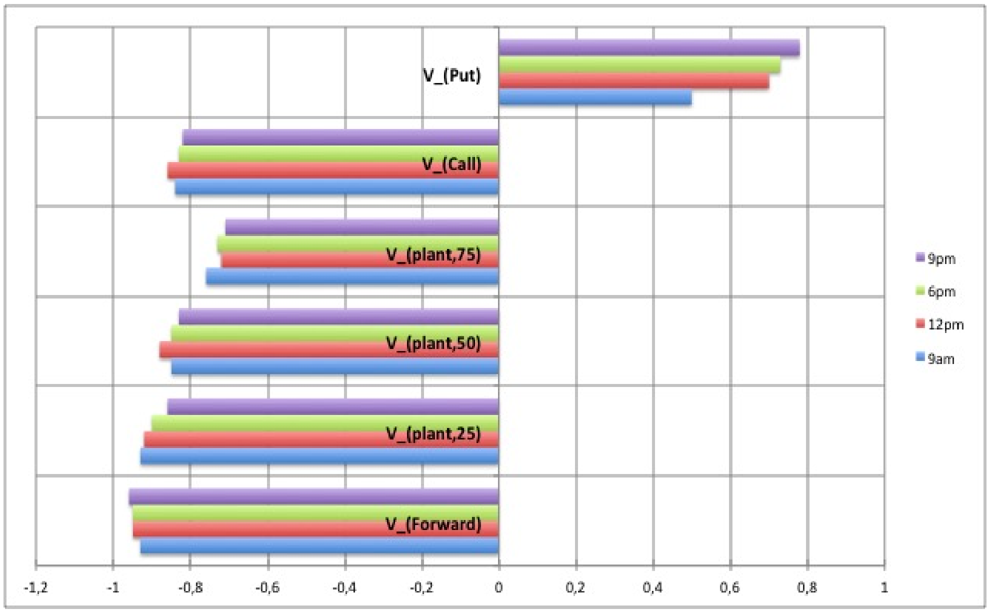
Table 10: Characteristics of the payoffs of the considered assets and correlation with retail for the 6pm cluster hour.

	Variance	VaR(95%)	Correlation with retail
Retail contract without hedge	277945,38	-843,59	1,00
$V_{forward}$	274045,55	-855,41	-0,95
$V_{plant,25}$	209721,64	-767,19	-0,90
$V_{plant,50}$	150929,70	-661,29	-0,85
$V_{plant,75}$	84828,13	-461,74	-0,73
V_{call}	134841,58	-600,76	-0,83
V_{put}	69776,88	-429,84	0,73

Table 11: Characteristics of the payoffs of the considered assets and correlation with retail for the 9pm cluster hour.

	Variance	VaR(95%)	Correlation with retail
Retail contract without hedge	129461,75	-604,96	1,00
$V_{forward}$	126929,01	-570,90	-0,96
$V_{plant,25}$	97570,33	-507,54	-0,86
$V_{plant,50}$	57427,23	-376,52	-0,83
$V_{plant,75}$	27382,66	-257,74	-0,71
V_{call}	51348,11	-356,81	-0,82
V_{put}	39344,62	-317,68	0,78

Figure 4: Characteristics of the payoffs of the considered assets and correlation with retail.



We clearly see that even if hedging a portfolio with "only forward" is inefficient compared to global hedging of a portfolio with financial options and physical assets, the correlation with retail is, for each cluster hour, highest with the payoffs of forwards (almost higher than $0,93$ in absolute value). For each cluster hour, the less correlated payoff is the put option.

Admittedly, hedging with forwards is sub-optimal. However, for all clusters, optimal portfolios always contain forwards, as measured by the VaR (Table 6). For the CVaR of the 6 pm cluster, the results are very close between the portfolios 'Only options' (CVaR of -362.08, Table 6) and 'Only forwards' (CVaR of -362.67, Table 4). In the same vein, for the 9 pm cluster, 'Only options' has a CVaR of -217.70 (Table 6) compared to -219.58 for the CVar of 'Only forward' (Table 5). Therefore, forwards are necessary but not sufficient for an optimal hedging.

Table 12: Optimal hedging portfolio for each cluster hour for different values of strike

		VaR		**CVaR**	
Hour	Strike	Optimal Hedging Portfolio	Value	Optimal Hedging Portfolio	Value
9am	+0	All possible contracts	-280.06	All possible contracts	-366,42
9am	+10	Forward + 3pp	-437.77	Forward and 3 plants	-755.81
9am	+20	Forward + 3pp	-437.77	Forward and 3 plants	-755.81
9am	+30	Forward + 3pp	-437.77	Forward and 3 plants	-755.81
9am	-10	Forward + 3pp	-437.77	Only Options	-735.68
9am	-20	Forward + 3pp	-437.77	All possible contracts	-746.50
9am	-30	Forward + 3pp	-437.77	6.0000	-755.81
12pm	+0	All possible contracts	-261.88	All possible contracts	-496,66
12pm	+10	Forward + 3pp	-589.32	3 plants	-1018,80
12pm	+20	Forward + 3pp	-589.32	3 plants	-1018,80
12pm	+30	Forward + 3pp	-622.54	Only forward	-1027,70
12pm	-10	Forward + 3pp	-589.32	3 plants	-1018,80
12pm	-20	All possible contracts	-587.72	3 plants	-1018,80
12pm	-30	All possible contracts	-572.47	3 plants	-1018,80
6pm	+0	Forward + 3pp	-273.47	Only Options	-362,08
6pm	+10	All possible contracts	-347.22	All possible contracts	-495.21
6pm	+20	All possible contracts	-348.95	All possible contracts	-491.21
6pm	+30	All possible contracts	-350.82	All possible contracts	-512.23
6pm	-10	All possible contracts	-381.67	Forward and 3 plants	-541.84
6pm	-20	All possible contracts	-382.38	Forward and 3 plants	-541.84
6pm	-30	All possible contracts	-382.40	Forward and 3 plants	-541.84
9pm	+0	Forward + 3pp	-168.04	Only Options	-217,70
9pm	+10	All possible contracts	-348.47	All possible contracts	-523.60
9pm	+20	All possible contracts	-331.82	All possible contracts	-512.09
9pm	+30	All possible contracts	-340.67	All possible contracts	-515.04
9pm	-10	All Contracts	-432.92	Forward and $V_{plant,75}$	-660.95
9pm	-20	Only Options	-440.96	Only Options	-660.95
9pm	-30	Only Options	-440.96	Forward and $V_{plant,75}$	-660.95

4.3 Optimal hedging portfolio for each cluster hour for different values of strike

We clearly see in Table 12 that the variation in optimal hedging strategy is not only in terms of VaR or CVaR values (i.e., we obtain results in the range of -622.54 to -168.04 for the VaR and from -1027.90 to -217.70 for the CVaR) but also in terms of the hedging portfolio. The optimal portfolios always include power plants or options. In fact, 14 of the 28 optimal hedging portfolios are "All Contracts", and 2 of the 28 are portfolios with "Only Options".

Efficient intra-day risk management should be performed against variations in total cost. A supplier's hourly profit is nonlinear in price given its exposition to the multiplicative risk of price and quantity. Consequently, hedging with linear payoff contracts is less efficient within markets with an hourly stochastic demand correlated to the spot price. Conversely, options and physical assets (specifically gas-fired plants) offer the operational flexibility required by electricity markets.

4.4 Benefits of using "out-of-the-money" options

The next Table 13 presents the benefits of using Options, especially "out-of-the-money" options.

Table 13: Benefits of using Options in hedging portfolios regarding the VaR(95%)

		Strike						
Hours	Delta	0	+10	+20	+30	-10	-20	-30
9am	All Contracts VS Without Options	-0,11%	-4,04%	-0,22%	-3,54%	-6,14%	-3,56%	-7,45%
9am	All Contracts VS Only Options	0,45%	6,16%	1,47%	2,58%	0,00%	0,94%	-2,25%
9am	Only Options VS Without Options	0,33%	2,21%	1,25%	-0,99%	-6,14%	-2,64%	5,32%
12pm	All Contracts VS Without Options	-8,41%	-0,05%	-0,09%	-0,01%	0,00%	-0,83%	-1,20%
12pm	All Contracts VS Only Options	11,38%	2,02%	3,57%	0,08%	0,16%	3,43%	-5,97%
12pm	Only Options VS Without Options	3,24%	1,97%	3,48%	0,07%	0,16%	2,62%	5,56%
6pm	All Contracts VS Without Options	-2,52%	-9,19%	-8,74%	-8,25%	-0,19%	0,00%	-6,13%
6pm	All Contracts VS Only Options	0,00%	18,26%	19,51%	19,35%	2,50%	5,52%	13,32%
6pm	Only Options VS Without Options	-2,52%	9,98%	11,80%	12,10%	2,31%	5,52%	7,65%
9pm	All Contracts VS Without Options	-0,87%	-20,97%	-24,75%	-22,74%	-1,82%	0,00%	0,44%
9pm	All Contracts VS Only Options	0,19%	13,37%	14,65%	12,10%	0,00%	0,00%	-0,44%
9pm	Only Options VS Without Options	-0,69%	-8,77%	-11,84%	-12,11%	-1,82%	0,00%	0,00%

We prove that hedging with options is an efficient strategy for all cluster hours. More specifically, "out-of-the-money" options minimize the portfolios' losses for the four clusters. For the 9 pm cluster, the VaR decreases up to 20%. Our results demonstrate the contribution of "out-of-the-money" options for intra-day hedging within volatile spot markets with price jumps.

The values of hedging in large power markets are strong. Through efficient hedging, retailers reduce their exposure to price spikes and subsequent joint quantity and price risk in hourly markets with strong volatility during peak hours. Climate warming targets should rely on the delivery of low carbon electricity by performing retailers that will benefit from the values of hedging to invest resources on energy transition. Indeed, electricity retailers are on frontline of climate change struggle. Precisely, risk hedging is central in the capacity of retailers to invest resources in renewables. By contributing to more efficient and less costly hedging, intraday hedging with options contribute to the delivery of low carbon energy at a lower risk premium for consumers. Moreover, it enables to optimize existing producing capacities, allocate more resources to high value-added energy efficiency services and investments in renewables. Therefore, hedging has concrete impacts on the structure of large power markets and the delivery of energy to consumers in order to fight global warming. A lower hedging cost enables to allocate more resources to digitalization and energy efficiency services to take into account customers? expectations for low carbon retailers. They become global energy services providers rather than solely energy sellers. By offering new tailored services, they are incited to innovate and maintain differentiation to keep their market shares and margins. This successful low carbon and innovative strategy relies on the use of intra-day hedging portfolios for mitigating volatility of electricity markets. The first step is to be able to hedge risk efficiently given the technical and economical specificities of hourly electricity markets.

5 Conclusion and policy recommendations

Our article provides a better understanding of risk management strategies for all energy market stakeholders. A good knowledge of efficient risk hedging strategies is not only important for electricity companies but also for regulators, policy makers, and investors in a context of climate emergency. Indeed, the electricity sector is key to achieve energy and ecological transition. Particularly, energy retailers are central to achieve a low carbon energy transition. They are a main lever given that, as market intermediaries, they interact both with producers and consumers. Consequently, they can influence the package of electricity sold to consumers. It remains less than 10 years for a radical reduction of greenhouse-gas emissions through international coordination. Electricity retailers should be on frontline of climate change struggle. However, they will be able to offer low carbon electricity if and only if they have efficient risk hedging strategies that take into account the technical and economic specificities of hourly electricity markets. By demonstrating the contribution of intra-day hedging with options and physical assets, we highlight the specificities of electricity markets as hourly markets with strong volatility during peak hours. We simulate a range of portfolio strategies in accordance with the statistical features of each cluster hour. The robustness of our results should support the development of liquid intra-day options. To enable efficient risk hedging without vertical integration, electricity retailers should be able to buy liquid options with intra-day maturities to mitigate production intermittency due to the increasing part of renewable energies in many countries. The linear hedging financial instruments are not appropriate to offer proper risk management and incite the development of renewables energies to maintain climate warming below 1.5 degrees Celsius by the end of the century. Intra-day hedging is a necessary condition to secure retailers' investments, debt capacity, and margins. Without intra-day hedging, consumers will pay high risk premiums and retailers will be hindered to invest in renewables and energy-efficiency services. By enhancing their financial performance, intra-day hedging portfolios are crucial to offer a low carbon electricity mix in accordance with low carbon emissions targets.

By defining optimal hedging strategies, our article proposes a range of new portfolios for electricity retailers to manage their risks and reduce their sourcing costs. A lower hedging cost enables to allocate more resources to digitalization and energy services to take into account customers expectations for more climate-friendly retailers. Electricity retailers can for instance offer more energy efficiency services to their customers by helping them to consume electricity in a more efficient way to reach the climate objectives. Electricity retailers become energy services providers rather than solely energy providers. By offering new tailored services, they are incited to innovate and maintain differentiation to keep their market shares and margins. This is a virtuous circle. Retailers provide high value-added energy efficiency services so that consumers consume less. The latter contributes to reach electricity reduction targets to fight climate warming.

Therefore, our article has strong policy implications in terms of regulation of electricity markets and liquidity of derivatives markets. If such liquidity is low, the volume of contracts traded will be an issue due to the lack of sufficient buyers and sellers in a given timeframe. To reach an appropriate liquidity, regulators and policy makers have to monitor carefully vertical integration strategies that can hinder not only the liquidity of electricity derivatives but also competitive dynamics in the framework of electricity market liberalization. Without efficient intra-day instruments, retailers are incited to vertically integrate which subsequently prevent the development of liquid intraday options in a setting of vicious circle. With dominant vertically integrated retailers in most countries, the contribution of electricity retail markets to the global performance of the electricity industry would remain very weak (Boroumand, 2015) given the lack of competition and weak consumers commitment to the market. Retail market liberalization was a huge institutional shock for electricity markets. By offering the opportunity for consumers to choose their retailers, retail competition should also contribute to a transition towards a low carbon economy in a framework of rising customers' climate expectations.

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