VIRTUAL POWER PURCHASE AGREEMENTS AND THEIR VALUE IN DECARBONISATION STRATEGIES

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Abstract

In order to be attractive to the capital market, companies are under increasing pressure to incorporate renewable energy (RE) targets into their business strategies. One of the most credible ways to demonstrate the renewable origin of electricity and to achieve a positive signalling effect is to enter into a power purchase agreement (PPA). A special form of this contract, the virtual PPA (VPPA), acts as a financial hedge, allowing the industrial buyer to achieve both a decarbonisation effect and a risk-minimising hedge. As the effect of a VPPA on the shareholder wealth of the electricity buyer has not yet been investigated in the literature, the purpose of this study is to fill this research gap. To this end, we analyse the abnormal stock returns of 89 VPPA announcements using a modified event study based on the Fama-French five-factor model (FFM5). Our results show significant positive abnormal returns around the announcement of a VPPA deal. This confirms the expectation that VPPAs are wealth-creating.

Keywords: Virtual Power Purchase Agreement, Shareholder Value, Decarbonisation, Sustainability, Event Study, Renewable Energy

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1. INTRODUCTION

Companies are under increasing pressure to integrate environmental, social and governance (ESG) objectives, into their business strategies, particularly since the introduction of regulatory measures such as the EU Taxonomy (Schütze & Stede, 2024). According to a Deutsche Bank survey of corporate issuers and investors, mainly in Europe and the U.S., the environmental aspect of ESG, and, therefore, reducing emissions and buying green electricity, is considered the most important of the three ESG factors (Templeman et al., 2021). According to the study, the main reason for pursuing ESG targets is the signalling effect on the company's stakeholders. In this regard, previous studies have found evidence that a higher environmental reputation leads to better access to capital markets via green finance instruments such as sustainability-linked loans (Pohl et al., 2023) and more durable sales channels (Nguyen-Viet, 2022). Against this backdrop, companies need to find ways to reduce their electricity-related Scope 2 emissions and document them in a way that is credible to stakeholders. According to Busch et al. (2016), the most credible and measurable contribution to sustainable development is the investment in renewable energy (RE) thereby becoming a RE producer itself. However, this option exposes the company to investment risk, including the risk of insufficient access to capital and the risk of lack of management and technical expertise (Gatzert & Kosub, 2016). In addition, generating electricity on or near the company's premises is subject to land restrictions (Simonelli, 2019). Entering into a power purchase agreement (PPA) is an alternative way to credibly contribute to sustainable development. PPAs are long-term bilateral contracts between an electricity producer and an industrial end-user for the supply of renewable electricity at a fixed price (Arellano & Carrión, 2023; Mendicino et al., 2019). In addition, virtual PPAs (VPPAs) enable the corporate buyer to directly access the energy attribute certificates (in Europe: guarantees of origin) of the respective RE asset in order to document the asset-specific origin of the electricity. VPPAs are, therefore, an important procurement channel for the documented decarbonisation of companies. In contrast to physical PPAs, VPPAs in particular do not involve the physical delivery of electricity from the seller to the buyer, but are purely a price hedge for the underlying amount of electricity (Hundt et al., 2022). In their basic form, they represent a hedging instrument against the volatility of the electricity prices. Besides the hedging effect, by entering into a VPPA, the buyer actively contributes to the connection of new RE capacity to the grid, as the closing of a VPPA is often a prerequisite for concluding project financing for the RE asset (Hundt et al., 2021).

In 2021, more than 30 GW of RE capacity was contracted under PPAs globally, up from less than 15 GW in 2018, thus making PPAs one of the fastest-growing alternatives to government-backed subsidy schemes for hedging electricity production from a seller's perspective, and thereby driving global decarbonisation (International Energy Agency [IEA], 2022). Alongside direct investments, the conclusion of a PPA is, therefore, one of the most 'additional' measures to contribute to sustainable development. The additionality principle reflects the actual impact of a procurement method on the addition of new RE capacity to the grid and thus on the progress of the energy transition (International Renewable Energy Agency [IRENA], 2018). Choosing procurement options with higher additionality, therefore, helps companies to make more credible statements about their RE procurement, increase the positive signalling effect and reduce the risk of greenwashing.

However, the effect of the conclusion of a VPPA on the shareholder wealth of the electricity buyer has not yet been investigated in the literature. Since a VPPA has two characteristic features in particular from the perspective of the industrial customer, namely 1) the long-term hedging of electricity procurement costs and 2) the possibility of decarbonising Scope 2 emissions, both of these factors can result in a positive wealth effect. So far, however, there are mixed empirical results in the literature on the impact of both characteristics on the shareholder wealth of corporate electricity consumers:

1. Regarding the hedging effect, various studies find positive wealth effects for firms that hedge exchange rates, but not for firms that hedge commodity prices (Bessler et al., 2019; Geyer-Klingeberg et al., 2021). Although studies such as Bachiller et al. (2021) and Carter et al. (2006) have found a positive correlation between the use of commodity hedges and company value, they did not focus in particular on investigating the electricity market.

2. Regarding the decarbonisation effect, studies such as Hulshof and Mulder (2020) and Pham et al. (2024) find no positive effect of the use of RE on the profits of the industrial energy buyer. On the contrary, studies like Shin et al. (2018) show that the use of RE leads to a better financial performance of a company compared to its industry peers. However, previous studies do not differentiate according to the additionality of the RE procurement method. When investigating additional procurement methods, such as mergers and acquisitions (M&A) deals involving RE assets, various previous studies, such as Wasilewski et al. (2021) and Salvi et al. (2018), document a positive market response.

Against this background, the question arises as to whether the conclusion of a VPPA has a positive shareholder wealth effect for the industrial energy buyer. This study aims to fill this research gap by analysing, using an event study, the abnormal stock returns of 89 VPPA announcements.

Therefore, the paper is structured as follows: Section 2 distinguishes a VPPA from a physical PPA and provides a literature review on the effect of hedging and decarbonisation on shareholder wealth. Section 3 describes the event study methodology used in the study. Section 4 describes the underlying data sample. The empirical results of the event study and the implications for listed corporate electricity buyers are described in Section 5. Finally, Section 6 concludes the paper.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Institutional end-users traditionally source RE from midstream intermediaries such as utilities or energy traders. Consequently, the potential to reduce the downstream buyer's Scope 2 emissions depends mainly on the share of RE in the intermediary's supply portfolio. As utilities and/or energy traders typically operate supply portfolios that also include a significant share of fossil fuels, the risk of greenwashing can negatively affect the image of institutional end users, especially in capital markets (Berrone et al., 2017; Kim, 2019; Marsat et al., 2022; Wong & Zhang, 2022). PPAs can be an alternative since these contracts allow the plant-specific origin of purchased electricity to be transparently documented. PPAs are defined as bilateral contracts between an electricity producer and a buyer for the supply of electricity at a predetermined price (Arellano & Carrión, 2023; Mendicino et al., 2019). In their basic form as a fixed-price contract, PPAs are not a novel but a traditional instrument for transferring market price risks (Bordo, 1980; Carlton, 1979). In contrast to traditional fixed-price contracts, PPAs are characterised by the fact that the underlying electricity supply comes from renewable sources (Gabrielli et al., 2022; Mendicino et al., 2019). The contractual partner supplying the electricity via a PPA is located in the upstream electricity value chain and, therefore, has an institutional affiliation as a project developer, RE investor or independent power producer (Mendicino et al., 2019). PPAs are, therefore, asset-specific contracts that enable buyers to prove the origin of their electricity purchases on an asset-specific basis by issuing guarantees of origin that are linked to the electricity flow. However, in principle, PPAs can be distinguished according to the way electricity is delivered:

1. *Physical PPAs*: In this case, the electricity is physically delivered from the RE asset owner to the buyer involving a balancing responsible party. As the producer's green electricity is mixed with grey electricity in the grid, the buyer physically consumes grey electricity but is able to prove that green electricity has been fed into the grid as a result of its commitment through the provided guarantees of origin.

2. *VPPAs*, on the other hand, do not involve the physical delivery of electricity from the seller to the buyer but are purely a price hedge for the underlying amount of electricity (Hundt et al., 2022). VPPAs are commonly structured as a Contract for Difference (CfD) which relates a fixed price (strike price) for future energy output of the RE asset to a variable market price (settlement price). Similar to physical PPAs, VPPAs also have a limited tenor and can include both, fixed or variable volume (Arellano & Carrión, 2023; Gabrielli et al., 2022).

By fixing the price of an underlying commodity *ex-ante* and offsetting the price movement of this underlying physical commodity transaction, VPPAs incorporate the characteristics of a financial hedge like unconditional derivatives such as futures or forwards (Dionne, 2013; Edge, 2014). In addition to providing a financial hedge, a VPPA achieves the same decarbonisation effect as a physical PPA for the same amount of green electricity by transferring the guarantees of origin and thus the asset-specific proof that the green electricity has been fed into the grid. Compared to physical PPAs, VPPAs have the advantage of being less complex to structure, as there is no need to involve a balancing responsible party (Tang & Zhang, 2019). In addition, VPPAs offer greater availability and geographical flexibility, as they can be concluded across national borders (so-called cross-border PPAs). These virtual cross-border PPAs can offer industrial customers the opportunity to decarbonise and hedge their electricity consumption in several countries through a single PPA, and to circumvent possible regulatory barriers in the markets where their load is located (World Business Council for Sustainable Development [WBCSD], 2020). Therefore, VPPAs can be observed more frequently, particularly in liberalised electricity markets such as those in North America (Chauhan, 2022; Mohseni Taheri et al., 2023). In line with this, the following study focuses on VPPAs. From a shareholder's perspective, the value of entering into a VPPA can generally be assessed from two perspectives: 1) as a risk-mitigating financial hedge in general or 2) as a decarbonisation instrument in particular.

2.1. VPPAs as a risk-mitigating hedge

The value of risk-mitigating financial hedges has become particularly evident during the energy crisis caused by the Russian invasion of Ukraine and the related gas supply disruptions. As a result of the increased price levels and higher price volatility, developing energy procurement strategies became a higher priority for a corporate strategy (European Commission, 2023; Crispeels et al., 2022). In this context, Bartram (2005) notes that firms exposed to commodity price fluctuations, in particular those in the metals, mining and oil and gas industries, tend to hedge this price risk through the use of financial derivatives such as VPPAs (Li & Flynn, 2004).

There are several studies that emphasise theoretical arguments, such as reducing the volatility of future cash flows and thereby reducing the cost of a firm's distress, as to why hedging, and, therefore, the conclusion of VPPAs, might increase firm value (Froot et al., 1993; Smith & Stulz, 1985). Despite these arguments, the empirical evidence on value enhancement through hedging is mixed. For example, Nelson et al. (2005) examine the effect of the use of derivatives for hedging purposes on the stock return performance of a sample of over 5,700 non-financial corporations. They find that hedging firms outperform other firms by an average of 4.3% per year. However, this superior stock market performance is only evident for firms that use currency derivatives, while the authors find little evidence of superior performance for firms that disclose commodity and/or interest rate derivatives. This is supported by Geyer-Klingeberg et al. (2021) and Bessler et al. (2019), who both conducted a meta-analysis of previous studies and found a positive wealth effect for firms engaged in exchange rate hedging, but none for firms engaged in commodity hedging (Jin & Jorion, 2006). In contrast, Bachiller et al. (2021), who also carried out a meta-analysis of 51 studies, found a positive and significant relationship between the use of derivatives and firm value for both foreign exchange and commodity hedging. Furthermore, Carter et al. (2006) investigate hedging of jet fuel prices in the U.S. airline industry and find a positive correlation with the firm value of the airline companies.

However, neither the studies that found a positive wealth effect nor the studies that did not find a positive wealth effect of commodity price hedging focus specifically on electricity markets. But since electricity markets are characterised by high price volatility, sometimes with irregular and inconsistent patterns, which are difficult to predict, there is a strong incentive for market participants to use hedging instruments as a risk management tool (Li & Flynn, 2004). In this market environment, VPPAs as a financial hedging instrument could, therefore, reduce a company's exposure to price volatility thereby increasing shareholder value.

2.2. VPPAs as a decarbonisation instrument

Beyond the general characteristics of a financial hedge, a VPPA as a decarbonisation tool in particular could also create value from the perspective of a company's shareholders. This decarbonisation effect of a VPPA can be a risk-mitigating factor in the sense that a firm's stakeholders increasingly monitor and evaluate its sustainability performance so that a negative ESG performance compared to competitors can result in an image risk. In this regard, Marsat et al. (2022) and Lorraine et al. (2004) show that environmental controversies, that is, negative news about the environmental impact of a company's activities, lead to a fall in share prices. Furthermore, a number of academic studies have shown that taking ESG measures can contribute to an increase in shareholder value (Friede et al., 2015;

Gómez-Bezares et al., 2017; Zumente & Bistrova, 2021). However, most of these studies measure sustainability based on indicator variables in a more holistic way, so it remains to be shown how the procurement of RE in general, or the conclusion of a VPPA in particular, affects shareholder value. In this context, studies focussing specifically on the procurement of RE and their impact on shareholder value have shown mixed results. For example, Hulshof and Mulder (2020) find no effect of RE use on firm profits. Furthermore, using a sample of Vietnamese firms, Pham et al. (2024) show that non-RE consumption has a positive effect on firm performance. Chung et al. (2024) find mixed results regarding the impact of the purchase of RE certificates (or guarantees of origin) on the stock returns of buyers. The authors conclude that the effect is positive for manufacturing firms, whereas it is not positive for companies from the service industry. On the contrary, the use of RE has been shown to lead to better financial performance of a firm relative to its industry peers in studies such as Shin et al. (2018) and Michalisin and Stinchfield (2010).

However, these studies do not differentiate according to the procurement method for RE and, therefore, also not according to the additionality of the companies' procurement measures. Compared to utility PPAs or the purchase of unbundled guarantees of origin that are usually investigated, there are two procurement options that provide a higher level of commitment to decarbonisation: 1) direct investments (M&As) and 2) PPAs. Both options offer the highest degree of additionality and, due to their asset specificity, also the highest degree of transparency. They are, therefore, the best possible option for communicating the decarbonisation strategy to stakeholders and, as public attention to environmental pollution is the most important factor associated with positive stock performance, realise the associated positive image effect (Chung et al., 2024). With respect to direct investments in RE, various previous studies such as Wasilewski et al. (2021) and Salvi et al. (2018) document a positive market response to M&A deals involving RE assets. Regarding PPAs, the study by Hundt (2023), which examines the wealth effect of signing a corporate PPA for the electricity buyer, finds that the conclusion of a corporate PPA induces a positive wealth effect for the shareholders of the electricity buyer. However, to the authors' knowledge, there are no studies that have examined the wealth effect of the conclusion of a VPPA in particular for the electricity buyer's shareholders.

Based on the above literature review, a two-part research gap, therefore, exists, namely 1) in the investigation of the shareholder wealth effect of hedging in the electricity market, and 2) in the investigation of the wealth effect of decarbonisation using a VPPA as a procurement instrument. On this basis, the following study aims to fill this research gap by analysing the wealth effect of concluding a VPPA for industrial buyers.

Based on the positive impact on a firm's environmental reputation and in line with the risk-mitigating features of a VPPA described above, we formulate the following null hypothesis:

H1: The announcement of a VPPA induces a significant positive wealth effect for the buyer's shareholders around the announcement date.

3. METHODOLOGY

Several studies have shown that the standard event study methodology which relies on the capital asset pricing model (CAPM), entails the risk of over- or underestimating stock returns (Cox & Britten, 2019; Zeren et al., 2019). In response to these shortcomings, Fama and French (2015) introduced their five-factor model to explain stock returns. According to the authors, the expected return $ER_{j,t}$ of a sample firm j at date t is calculated as follows:

$$ER_{j,t} = \alpha_{(5F)} + \beta_{j,MKT}(R_{m,t} - R_{f,t}) + \beta_{j,SMB}SMB_t + \beta_{j,HML}HML_t + \beta_{j,RMW}RMW_t + \beta_{j,CMA}CMA_t + \varepsilon_{j,t} \quad (1)$$

The variable $\alpha_{(5F)}$ is the intercept of the regression equation and represents the component of the return that is not market-related. The beta factors are measures of the sensitivity of the five factors in Eq. (1) and may reflect the volatility of a particular stock relative to the market portfolio. $\varepsilon_{j,t}$ is the zero mean residual representing the random component of a return due to unexpected events associated with a given portfolio. Generally, $\varepsilon_{j,t}$ has a multivariate normal distribution and is identically and independently distributed over time. $(R_{m,t} - R_{f,t})$ is defined as the risk premium and is generally positive. The Fama-French five-factor (FFM5) factors are calculated daily within the 250 trading day window prior to the event window. Since, according to Fama and French (1993), the returns of smaller companies are expected to be higher than the returns of larger companies, SMB_t reflects the difference in stock returns between the portfolios of small and large companies. Size is thereby measured by the market capitalisation of the sample companies. The HML_t factor reflects that the stock returns of companies with a high book-to-market ratio will be higher than the stock returns of companies with a low book-to-market ratio. As part of their three-factor model (FFM3), Fama and French (1993) call the two factors SMB_t and HML_t "mimicking returns". Both are used as approximations for non-diversifiable risk factors that are not taken into account by the CAPM. The empirical evidence for the robustness of the FFM3 in explaining stock returns is mixed. Van Dijk (2011) has confirmed the robustness of the FFM3 in explaining stock returns, while Novy-Marx (2013) suggests that other factors, including the company's earnings expectations and investment behaviour, may also have an impact on expected stock returns. This was also suggested by the earlier studies Fama and French (2006) and Fama and French (2008) before Fama and French (2015) introduced two additional factors, "robust minus weak" (RMW_t) and "conservative minus aggressive" (CMA_t), to include profitability and investment. RMW_t compares the returns of companies with high operating profitability to those with low operating profitability. CMA_t takes into account the company's investment behaviour by measuring the difference in returns between companies that pursue riskier investments and those that adopt a more conservative investment approach. For the U.S. market in particular, Horváth and Wang (2021) confirm that the introduction of the two factors provides greater explanatory power and more robust abnormal returns compared to the FFM3 and CAPM. Also, Foye (2018) finds that the five-factor model outperforms the three-factor model in the emerging markets of Eastern Europe and Latin America. Chai et al. (2019) find that FFM5 outperforms FFM3 and CAPM, among others, when comparing the performance of a range of competing factor models in pricing large Australian stocks.

Previous studies have shown that the statistical power of the FFM5 depends on the geographical composition of the underlying sample. Griffin (2002) finds that the FFM5 has greater country-specificity and provides robust results for the U.S. market, while its analytical power varies for non-U.S. markets. However, studies by Zeren et al. (2019) for Turkey, Cox and Britten (2019) for South Africa, and Huang (2019) for China conclude that the FFM5 remains valid and explains variations in expected and abnormal returns accordingly. In contrast, Dirkx and Peter (2020) show that the FFM5 does not add any explanatory value to the German stock market. However, since the sample in this study consists mainly of US-listed companies, the FFM5 is considered to be applicable from a geographical point of view.

After calculating the expected return based on the FFM5, the abnormal return $AR_{j,t}$ of the sample company *j* at time *t* is calculated using the methods of Brown and Warner (1980, 1985):

$$AR_{j,t} = R_{j,t} - ER_{j,t} \tag{2}$$

The variable $R_{j,t}$ is sample company *j*'s real stock return at date *t*. Abnormal returns are then aggregated within the event window $[\mathrm{T}_1, \mathrm{T}_2]$ and calculated as cumulative abnormal returns $CAR_{[T_1,T_2]}$ (CAR), i.e.:

$$CAR_{[T_1,T_2]} = \frac{1}{N}\sum_{j=1}^{N}\sum_{t=T_1}^{T_2} AR_{j,t} \tag{3}$$

A four-step extension of the event study approach is used to improve the statistical power of the regression results. In the first step, the choice of the market index used to compute $R_{j,t}$ in Eq. (2) is optimised according to maximising R^2. Early studies such as Brown and Warner (1980, 1985) pointed out that the choice of market index can affect the quality of the regression. The FFM5 is run on the basis of the MSCI World Index. $ER_{j,t}$ is also calculated based on the national stock market index according to the country-specific part of the International Securities Identification Number (ISIN) number of the sample company. This results in two-time series for the same sample company, which are then compared in terms of their coefficients of determination. The index with the higher R^2 is then used.

Second, to further improve the regression quality, a robust regression method is applied to the index-optimised time series. Due to unidentified confounding events and macroeconomic effects, statistical outliers, meaning observations that do not follow the pattern of the majority of the data and thus have a relatively large distance from the centre of the point cloud, may bias the regression model (Park, 2004; Rousseeuw & van Zomeren, 1990). The conclusion of Sorokina et al. (2013) is that previous event studies do not adequately address this problem. Therefore, following the methodology of Hundt et al. (2017), this study also applies robust regression according to Rousseeuw (1984), Rousseeuw and Leroy (1987) and Mount et al. (2014). To calculate the regression coefficients β_{LTS} a least trimmed square regression (LTS) is used instead of the ordinary least squares (OLS) regression used in standard event study approaches, i.e.:

$$\beta_{LTS} = arg\min_{\beta \in R^{\varepsilon}} \sum_{n=1}^{N-h} (\varepsilon_n(Y, X_i, \beta))^2 \tag{4}$$

The variable $\varepsilon_n(Y, X_i, \beta)$ is the absolute residual of observation *n* within the total sample of *N* observations. The LTS method sorts the residuals according to their absolute value, resulting in the ranking $\varepsilon_1(Y, X_i, \beta) \leq \varepsilon_2(Y, X_i, \beta) \leq \cdots \leq \varepsilon_N(Y, X_i, \beta)$. h represents the number of outliers to be removed. Therefore, when $h = 0$, LTS and OLS give the same results. Assuming $h < N$, the number of abnormal returns with the highest residuals (N - h) are eliminated from the regression sample *N*. The main advantage of robust regression methods is the achievement of a higher breakdown value.

Contributing to the heteroskedasticity of abnormal returns is the third step in improving the statistical robustness of the calculated abnormal returns. According to Mikkelson and Partch (1988), the volatility of $CAR_{[T_1,T_2]}$ can be biased by substantial cross-section variance. Furthermore, time series with a high variance of abnormal returns may bias statistical tests. Therefore, the standardised cumulative abnormal return $SCAR_{[T_1;T_2]}$ (SCAR) within the event window [T1, T2] was introduced by Patell (1976) and Mikkelson and Partch (1988):

$$SCAR_{[T_1,T_2]} = \frac{1}{N}\sum_{j=1}^{N} SCAR_{j,[T_1,T_2]} = \frac{1}{N}\sum_{j=1}^{N}\frac{\sum_{t=T_1}^{T_2} AR_{j,t}}{\hat{\sigma}(AR_{j,t})} \tag{5}$$

$$\hat{\sigma}(AR_{j,t}) = \sqrt{\frac{1}{ED_j - 2}\sum_{t=-230}^{-11}\left(AR_{j,t} - \frac{1}{ED_j}\sum_{t=-230}^{-11} AR_{j,t}\right)^2} \tag{6}$$

where, $SCAR_{j,[T_1,T_2]}$ is the standardized cumulative abnormal return of time series *j* and $\hat{\sigma}(AR_{j,t})$ is the standard deviation of abnormal returns $AR_{j,t}$. ED_j denotes the number of trading days within the regression window [-230; -11].

In the final step, four different significance tests and a test of the distribution of abnormal returns are used to analyse the statistical significance of the abnormal returns. Statistical significance is analysed by means of the t-test, the Wilcoxon sign rank test and the generalised rank test (GRANK) according to Kolari and Pynnonen (2011). As a fourth significance test, the analysis includes a bootstrap method according to Efron (1992) and Di Cesare (2006) for 1,000 populations, as the previous three tests are based on certain distributional assumptions. The analysis of the distribution of abnormal returns is carried out by applying the Shapiro-Wilk test, since this test has a better performance when the sample size is small and medium (Shapiro & Wilk, 1965).

The analysis of abnormal stock returns of the VPPA buyer takes place over a period of 21 trading days around the announced closing date. The symmetric event window [-10; 10] is divided into three pre-announcement windows [-10; 0], [-5; 0], [-1;0] and three post-announcement windows [0; 1], [0; 5], [0; 10]. Following several previous studies, the analysis is mainly based on the event window [-1; 1] (Han et al., 2009; Nerlinger & Utz, 2022). Besides FFM5, FFM3 and CAPM are also used as benchmarks in this empirical analysis.

4. SAMPLE AND DATA DESCRIPTION

The study is based on a sample of 329 announced PPAs worldwide. These were compiled using data from Bloomberg New Energy Finance, Thomson Reuters Eikon and public sources, including press releases from industrial power buyers. The determination of the official announcement date is mainly related to press releases of the electricity buyers. Bloomberg New Energy Finance was used to identify a list of potential VPPA deals since this database has a specific category that is focused solely on PPA markets worldwide. Moreover, we used Thomson Reuters Eikon for investigating additional descriptions for each sample company which is used in the multivariate regression analysis, e.g., credit ratings. In sum, the motivation for using these leading data providers was to have a multiple-step approach to verifying single data points. Especially for event studies, this approach is crucial to avoid the integration of confounding events which may strongly distort the results of the analysis.

In a first step, the database was screened for the transaction and structuring details of the completed PPA transactions and all physical PPAs and those without known transaction details were excluded. For each individual virtual corporate PPA announced, the precise announcement date and possible confounding events such as the announcement of M&As, changes in credit rating, etc., were searched for in the event window. After excluding the data points that were unusable due to confounding events, the analysed sample shown in Table 1 consists of 89 VPPAs that were publicly announced between 2010 and 2020 via press releases from industrial buyers. In order to increase the robustness of the analysis, a peer group was constructed using data from Thomson Reuters Eikon. This peer group contains a benchmark company for each company in the sample, which is comparable in terms of total assets and industry sector. The industry classification is based on the Standard Industrial Classification (SIC). However, the peer group composition differs in terms of geographical distribution. As displayed in Table 1, 96% of announcements were made by companies which are headquartered in the U.S. while the benchmark sample shows 71%. The VPPA sample also contains firms from Belgium, Denmark, and Great Britain. In contrast, the benchmark sample composition is as follows: 9% Israel, 4% Ireland, 2% Brazil, 2% Canada, 2% China, 2% Great Britain, 2% Japan, 2% the Netherlands, 2% South Korea 2%, and 1% Spain. The peer companies did not announce any PPA agreements during the period analysed. However, the abnormal returns of the peer group companies are calculated by using the same announcement date as being used in the VPPA sample.

Table 1. Sample description

Panel name	*#*	*in %*
Panel A: Country of stock exchange		
Belgium	2	2%
Denmark	1	1%
Great Britain	1	1%
United States	85	96%
Panel B: Announcement year		
2008	0	0%
2009	0	0%
2010	1	1%
2011	0	0%
2012	2	2%
2013	1	1%
2014	1	1%
2015	9	10%
2016	8	9%
2017	7	8%
2018	18	20%
2019	34	38%
2020	8	9%
Panel C: Buyside industry sector		
Datacenter provider	26	29%
Energy & oil	3	3%
Financial services	6	7%
Leisure & tourism	1	1%
Manufacturer & industrials	28	31%
Retailer & e-commerce	20	22%
Telecommunication	5	6%
Panel D: Sell-side technology		
Solar	34	38%
Wind	55	62%
Panel E: Renewable energy asset capacity		
Small (X < 50 MW)	17	19%
Medium (50 MW <= X < 100 MW)	20	22%
Large (X >= 100 MW)	52	58%
Panel F: Buyside credit rating		
High	22	27%
Medium	44	54%
Low	16	20%
Panel G: Buyside sustainability rating		
High	37	42%
Medium	42	48%
Low	9	10%

Note: N = 89. The table shows the analysed sample of 89 virtual PPA announcements. Panel A shows the country in which the power buyers that announced a VPPA are listed. Panel B shows the year of the virtual PPA announcement. Panel C shows the industrial sectors to which the electricity buyers belong. Panel D shows the technology of the RE asset with which a VPPA was concluded. Panel E shows the size of the RE asset with which a VPPA was announced. Panel F shows the credit rating of the buyers, categorised as follows: High — from AAA to AA-; Medium — from A+ to BBB-; Low — from BB+ to C. Panel G shows the buyer's sustainability rating as assessed by MSCI (MSCI) ESG Ratings and Sustainalytics, two of the leading sustainability rating agencies. As both agencies use different rating scales, these ratings are categorised according to their rating manuals as follows: High (MSCI) — from AAA to AA; High (Sustainalytics) — from 100 to 55; Medium (MSCI) — from A to BB; Medium (Sustainalytics) — from 54.9 to 35; Low (MSCI) — from B to CCC; Low (Sustainalytics) — from 34.9 to 0.

Thomson Eikon and Datastream were used to obtain the daily share prices of the sample companies and the index data. The expected returns in the following analysis are calculated using the MSCI World Index and national stock indices.

At 96%, the vast majority of industrial buyers in the sample are listed in the U.S. This is due to the fact that the U.S. is the most developed PPA market globally, with the highest number of PPA transactions involving solar or wind farms during the period covered by the sample (Henze, 2022). Regarding the industrial sector, the majority of sampled industrial electricity consumers are companies from energy-intensive sectors such as industry & manufacturing or data centres. together with the electricity purchasers from the e-commerce & retail sector, these sectors account for more than 80% of the total data sample. More than 50% of the VPPA transactions of the sample are closed with large RE assets with an installed capacity of more than 100 MW.

As the conclusion of a PPA is often a prerequisite for obtaining project finance for a new RE asset, banks require industrial buyers with a high credit rating in order to secure the long-term sales channel for the asset from which the future debt service will be paid (Campbell & Meyers, 2018; Hundt et al., 2021). The underlying data sample, therefore, consists of industrial buyers with mostly medium or high credit ratings, meaning ratings between A+ and BBB-. The classification "High" means a credit rating from AAA to AA-, the classification "Low" includes all ratings between BB+ and C. Where ratings are split, the lower rating has been selected for conservative analysis.

In addition to the credit ratings, the sustainability ratings of the buyers were also included in the analysis. The majority of industrial buyers signing PPAs are actively committed to their decarbonisation strategy and, therefore, often have a good to medium sustainability rating. In the underlying sample, this applies to 90% of buyers. To measure the ratings, MSCI uses an ordinal scale, while Sustainalytics uses a cardinal scale. A rating is "High" between AAA and AA and 100 to 55. "Medium" ESG ratings are between A and BB or 54.9 to 35. Finally, "Low" ESG ratings are between B and CCC or 34.9 to 0.

5. RESULTS

Table 2 shows the CARs as well as the SCARs across different symmetric and asymmetric event windows around the date when the closing of a VPPA was announced. In the announcement window [-1; 1], we find positive abnormal returns of 0.5518% (*SCAR* = 0.2524) that are statistically significant at least at the 5% level in all parametric and non-parametric tests applied. This suggests that shareholders of listed energy buyers see wealth creation potential in the signing of a VPPA. However, whether this wealth creation is driven by the described cost-saving potential (hedging character) and/or the environmental impact (sustainability character) of VPPAs cannot be conclusively assessed at this stage of the analysis and will be analysed in the multivariate analysis section. Nevertheless, the result already shows that a VPPA has the potential to improve the corporate energy buyer's stock market position, at least in the short term.

Table 2. Abnormal returns of VPPA announcements

Regression model	*Symmetric event windows*			*Pre-announcement windows*			*Post-announcement windows*		
	[-1; 1]	*[-5; 5]*	*[-10; 10]*	*[-1; 0]*	*[-5; 0]*	*[-10; 0]*	*[0; 1]*	*[0; 5]*	*[0; 10]*
CAPM									
CAR in %	0.3422	-4.2927	-5.9395	0.3134	-1.9644	-2.1253	0.7774	-1.5797	-3.0656
SCAR	0.3215	-1.6008	-1.5246	0.4175	-1.0824	-0.8402	0.8282	-0.8632	-1.1705
Shapiro-Wilk	0.0005***	0.0014***	0.0037***	0.4454	6.7904e-7***	5.9948e-5***	0.0001***	2.6809e-5***	3.1030e-6***
t-test	0.0130**	0.1004	0.7375	0.0586	0.1804	0.8765	0.0183**	0.1105	0.2967
Wilcoxon sign rank test	0.0161**	0.0785	0.4393	0.0519	0.0066***	0.6824	0.0246**	0.1642	0.3680
GRANK	0.0091***	0.0948	0.4203	0.0227**	0.0258**	0.5864	0.0239**	0.1321	0.3728
Bootstrap	0.0040***	0.0700	0.6979	0.0620	0.2240	0.8759	0.0060***	0.0900	0.2660
Fama French three-factor (FFM3)									
CAR in %	0.4955	0.5890	0.1461	0.3023	0.5055	0.0733	0.4066	0.2970	0.2862
SCAR	0.2137	0.1510	0.0166	0.1900	0.1506	-0.0265	0.1682	0.1134	0.0862
Shapiro-Wilk	0.0043***	0.1424	0.0056***	0.0043***	2.4338e-6***	0.0009***	0.0036***	0.0044***	0.0002***
t-test	0.0601	0.1701	0.8759	0.0928	0.1652	0.8008	0.1244	0.2984	0.4275
Wilcoxon sign rank test	0.0966	0.1890	0.3835	0.1463	0.0320**	0.7558	0.2605	0.3281	0.4417
GRANK	0.0647	0.1770	0.4187	0.0823	0.0354**	0.6768	0.2313	0.2290	0.4025
Bootstrap	0.0480**	0.1719	0.8840	0.0800	0.1719	0.7680	0.1180	0.2700	0.4160
Fama French five-factor (FFM5)									
CAR in %	0.5518	0.4493	0.0938	0.3049	0.3815	-0.0038	0.5057	0.3265	0.3563
SCAR	0.2524	0.1225	0.0183	0.2043	0.1100	-0.0326	0.2345	0.1239	0.1102
Shapiro-Wilk	0.0414**	0.0246**	0.0394**	0.1564	5.7751e-7***	5.3603e-5***	0.0160**	3.6603e-6***	0.0001***
t-test	0.0216**	0.2523	0.8638	0.0654	0.3042	0.7588	0.0315**	0.2452	0.3052
Wilcoxon sign rank test	0.0210**	0.2819	0.6119	0.0778	0.0887	0.7620	0.0274**	0.2640	0.2819
GRANK	0.0019***	0.1997	0.5993	0.0302**	0.0451**	0.6072	0.0166**	0.1640	0.2593
Bootstrap	0.0080***	0.2300	0.8520	0.0600	0.4040	0.7700	0.0120**	0.2380	0.2760

*Note: N = 89. The table shows the cumulative average abnormal returns (CAR) and the standardised cumulative average abnormal returns (SCAR) for three symmetrical and six asymmetrical event windows around the date of a VPPA announcement for the sample. *** indicates a statistical significance on at least a 1 % level, ** indicates a statistical significance on at least a 5 % level.*

As shown in Table 2, we also find significant abnormal returns in the CAPM model whereas only the Bootstrap according to Di Cesare (2006) shows significant abnormal returns on a 5% level for the FFM3. In contrast, the peer group sample shows no significant abnormal returns in all windows examined, including the announcement window [-1; 1], underlining that the announced closing of a VPPA can have positive signalling effects on stock markets (see Table 3).

Table 3. Abnormal returns of peer group

Regression model	Symmetric event windows			Pre-announcement windows			Post-announcement windows		
	[-1; 1]	[-5; 5]	[-10; 10]	[-1; 0]	[-5; 0]	[-10; 0]	[0; 1]	[0; 5]	[0; 10]
CAPM									
CAR in %	0.1575	-1.2746	-10.2218	-0.3112	3.3526	-1.4701	-2.3253	-4.8541	-8.9787
SCAR	0.0351	-0.0123	-0.0834	-0.1090	0.0004	-0.1579	-0.0252	-0.0071	-0.0583
Shapiro-Wilk	0.0098***	0.0238**	0.7003	0.0133**	0.0050***	0.0981	3.2267e-5***	0.1567	0.4716
t-test	0.7436	0.9077	0.4184	0.3130	0.9970	0.1269	0.8155	0.9480	0.5825
Wilcoxon sign rank test	0.8029	0.5557	0.5807	0.1133	0.8219	0.2710	0.6350	0.9804	0.4892
GRANK	0.7163	0.3380	0.4782	0.0429**	0.8361	0.2807	0.6365	0.9875	0.3534
Bootstrap	0.7900	0.9460	0.4359	0.3280	0.9840	0.1060	0.7700	0.8980	0.6060
Fama French three-factor (FFM3)									
CAR in %	0.1219	-0.1231	-0.0021	0.3119	0.0965	-0.2203	-0.1511	-0.1808	0.0530
SCAR	0.0481	-0.0005	-0.0756	0.1169	0.0075	-0.1458	-0.0165	-0.0201	0.0575
Shapiro-Wilk	0.0163**	0.0142**	0.7165	0.0073***	0.0068***	0.0954	6.6754e-5***	0.1250	0.5232
t-test	0.6570	0.9963	0.4609	0.2798	0.9442	0.1583	0.8801	0.8545	0.5850
Wilcoxon sign rank test	0.6704	0.6409	0.6645	0.0895	0.9120	0.3658	0.7127	0.9152	0.4540
GRANK	0.6449	0.4215	0.5288	0.0419**	0.9106	0.3520	0.6729	0.9412	0.3619
Bootstrap	0.6560	0.9580	0.4800	0.2960	0.9180	0.1200	0.8819	0.8840	0.5840
Fama French five-factor (FFM5)									
CAR in %	0.2016	-0.0559	-0.0076	0.3859	-0.2729	-0.2108	-0.0290	-0.0618	0.3737
SCAR	0.0358	-0.0204	-0.0901	0.1126	-0.0073	-0.1616	-0.0285	0.0021	0.0519
Shapiro-Wilk	0.0116**	0.0504	0.7240	0.0104**	0.0068***	0.0685	2.1211e-5***	0.1358	0.5289
t-test	0.7411	0.8478	0.3808	0.3007	0.9456	0.1196	0.7936	0.9843	0.6235
Wilcoxon sign rank test	0.7527	0.5807	0.5530	0.0934	0.8092	0.2782	0.6321	0.9738	0.5286
GRANK	0.7206	0.3231	0.4828	0.0379**	0.7829	0.2902	0.6244	0.9658	0.3957
Bootstrap	0.7400	0.8759	0.3560	0.2980	0.9460	0.1020	0.8200	0.9360	0.6460

*Note: N = 89. The table shows the cumulative average abnormal returns (CAR) and the standardised cumulative average abnormal returns (SCAR) for three symmetrical and six asymmetrical event windows around the date of a VPPA announcement for the peer group. *** indicates a statistical significance on at least a 1 % level, ** indicates a statistical significance on at least a 5 % level.*

By splitting the announcement window into two asymmetric windows [-1; 0] and [0; 1], we observe that significant abnormal returns amount to 0.5057% (*SCAR* = 0.2345) in the post-announcement window [0; 1]. Our results, therefore, suggest that the signing of a VPPA was assessed *ex-post* and not anticipated by shareholders prior to the official announcement. On the one hand, this may be because no information about bilateral VPPA negotiations is made available to the shareholders prior to the public announcement. On the other hand, VPPAs are a relatively new form of hedging against volatile electricity market prices while improving the company's environmental reputation. The novelty of these agreements as a contractual solution to the company's decarbonisation strategy seems to mean that their value will only be assessed *ex-post* by investors. Similar to the [-1; 1] announcement window, we also find significance for CAPM-based abnormal returns in the post-announcement window, while we do not find significant returns for the FFM3. Furthermore, the post-announcement effect is underlined by the lack of significance in the control group sample. In summary, we accept the formulated *H1* that a VPPA announcement induces positive shareholder wealth effects around the announcement date.

The multivariate analysis examines various independent variables that may influence abnormal returns, as shown in Table 4.

Table 4. Multivariate regression analysis

Independent variables	Announcement window
	[-1; 1]
RE asset capacity (*CAPA*)	$1.40\ 10^{-3}$
	(1.01)
RE producer technology (*TEC*)	-0.6480**
	(-2.59)
Country of RE producer (*LAND*)	-0.0772
	(-0.13)
Sustainability rating (*ESGR*)	-0.0298
	(-0.16)
Credit rating (*RAT*)	0.1320
	(0.67)
Debt ratio (*DEBR*)	0.7228
	(0.93)
Liquidity ratio (*QUIR*)	-0.4950
	(-0.96)
Total assets (*TOTA*)	$-2.30\ 10^{-7}$
	(-0.51)
Adj. R^2 in %	8.9

*Note: The table shows the regression coefficients of the independent variables. CAPA is the installed capacity of renewable energy assets in MW. TEC is a dummy variable that takes the value 1 for onshore wind farms and 0 for utility-scale solar plants. LAND is defined as the country in which the renewable energy storage asset is located. As the U.S. market is the largest market for PPAs, this variable takes the value of 1 if the asset is located in the U.S. and 0 if the asset is located in a market outside the U.S. ESGR refers to the off-taker's sustainability rating provided by MSCI ESG Ratings and Sustainalytics. RAT refers to the off-taker's issuer credit rating provided by Standard & Poor's, Moody's and Fitch. DEBR is the off-taker's debt ratio and is defined as total long-term debt divided by total assets. QUIR is the off-taker's quick ratio and is defined as the sum of primary liquidity and outstanding receivables divided by the sum of short-term liabilities. TOTA is defined as the total assets of the off-taker, which is used as a functional variable for the size of the company. The adjusted R^2 is used as a proxy for the quality of the regression. *** indicates a statistical significance on at least a 1 % level, ** indicates a statistical significance on at least a 5 % level.*

We use heteroskedasticity-consistent t-statistics to examine the influence of the independent variables. The regress model is also based on the LTS approach and is represented by the following formula:

$$SCAR_{j,[T_1,T_2]} = \beta_0 + \beta_1 CAPA_j + \beta_2 TEC_j + \beta_3 LAND_j + \beta_4 ESGR_j + \beta_5 RAT_j + \beta_6 DEBR_j + \beta_7 QUIR_j + \beta_8 TOTA_j + \varepsilon_j \quad (7)$$

Analogous to the FFM5 approach, we accept a result as being statistically significant on at least a 5% level. $CAPA_j$ represents the capacity of the RE plant and does not show any significance. TEC_j is a dummy variable that equals 1 if the seller is an onshore wind farm or 0 if it is a utility-scale solar plant. The regression coefficient is -0.648 and is significant at the 5% level. This result indicates that the SCAR becomes less positive for onshore wind farms. This may be due to the fact that, according to Hassan et al. (2023), onshore wind production is less predictable than solar production. As most VPPAs are concluded as as-produced PPAs, i.e., without a volume guarantee from the seller, the volume risk lies with the electricity buyer. If actual production is lower than expected, the buyer is exposed to the risk of under-hedging under the VPPA. Onshore wind PPAs may, therefore, offer less hedging potential than solar PPAs due to the greater variability of the wind resource, and, therefore, may create less value from a shareholder perspective.

The following independent variables are not statistically significant. $LAND_j$ refers to a dummy variable that equals 1 if the VPPA was closed in the U.S. and 0 for non-U.S. markets, as the U.S. is the largest VPPA market (Chauhan, 2022). $ESGR_j$ is the ESG rating of the buyer and RAT_j is the credit rating. These variables have been examined because the VPPAs are usually entered into by larger companies with a good ESG rating and an investment-grade credit rating. $DEBR_j$ is defined as the debt ratio which is calculated as total long-term borrowing divided by total assets. This variable was chosen to investigate potential changes in credit risk in more detail. $QUIR_j$ is the buyer's quick ratio, defined as the buyer's cash and outstanding receivables divided by the sum of current liabilities. We examined this variable to assess the buyer's ability to pay compensation if market prices fall below the strike price. Finally, $TOTA_j$ represents the buyer's total assets which is used to investigate the influence of the buyer's company size, as VPPAs are mostly concluded with large blue chips.

6. CONCLUSION

Closing a VPPA is one of the most 'additional' procurement methods for industrial energy buyers to contribute to sustainable development. Signing a VPPA can, therefore, improve the environmental performance of an electricity consumer, help to reliably document the active role played in adding new RE capacity to the grid while providing a hedge against price volatility in energy markets. Both effects of a VPPA, the decarbonization and the hedging effect, can have a positive impact on a company's shareholder value. Therefore, the announcement of a closed VPPA can be expected to be wealth-creating for the shareholders of listed electricity consumers. To investigate this announcement effect of a VPPA closing, we developed an event study based on the Fama-French five-factor model including a robust regression approach and analysed 89 VPPA announcements. Our results show significant positive abnormal returns around the announcement of a VPPA deal. Thus, we can confirm the initial expectation that the signing of VPPAs is wealth-creating from a shareholder perspective. This effect on an industrial buyer's abnormal return is less positive for onshore wind, indicating that shareholders value the fact that solar energy is more predictable than wind energy, thereby contributing to the security of supply. However, for both RE technologies, the results show that sustainable investments create incentives for industrial electricity consumers to actively contribute to the decarbonisation of electricity-related Scope 2 emissions and the expansion of RE. This requires regulators to create a market environment in which market-based alternatives to state subsidies, such as VPPAs, can be realised and contribute to achieving the energy system transformation.

By investigating the perceptions of an industrial company's shareholders of a VPPA closing, our study adds to the existing literature, which mainly examines RE procurement methods such as green tariffs or direct investment. Major limitations of our study include the concentration of the sample in the most developed PPA market worldwide, the U.S. Therefore, to complement our study, future research should focus on markets outside the U.S. to investigate whether the same shareholder wealth effect can be demonstrated in less developed but growing PPA markets in Europe or Asia. In addition, future research should extend the sample to the period during and after the European energy crisis, caused by the Russian invasion of Ukraine and the associated gas supply disruptions, to investigate whether the greater focus on security of supply has strengthened the valuation of VPPAs from a shareholder perspective. In this context, future studies should focus on VPPA transactions that achieve greater diversification and thus security of supply through the combination of wind and solar assets or the inclusion of storage solutions such as batteries and hydrogen.

REFERENCES

Arellano, J., & Carrión, M. (2023). Electricity procurement of large consumers considering power-purchase agreements. *Energy Reports, 9*, 5384–5396. https://doi.org/10.1016/j.egyr.2023.04.371

Bachiller, P., Boubaker, S., & Mefteh-Wali, S. (2021). Financial derivatives and firm value: What have we learned? *Finance Research Letters, 39*, Article 101573. https://doi.org/10.1016/j.frl.2020.101573

Bartram, S. M. (2005). The impact of commodity price risk on firm value — An empirical analysis of corporate commodity price exposures. *Multinational Finance Journal, 9*(3–4), 161–187. https://doi.org/10.17578/9-3/4-2

Berrone, P., Fosfuri, A., & Gelabert, L. (2017). Does greenwashing pay off? Understanding the relationship between environmental actions and environmental legitimacy. *Journal of Business Ethics, 144*(2), 363–379. https://doi.org/10.1007/s10551-015-2816-9
Bessler, W., Conlon, T., & Huan, X. (2019). Does corporate hedging enhance shareholder value? A meta-analysis. *International Review of Financial Analysis, 61*, 222–232. https://doi.org/10.1016/j.irfa.2018.11.010
Bordo, M. D. (1980). The effects of monetary change on relative commodity prices and the role of long-term contracts. *Journal of Political Economy, 88*(6), 1088–1109. https://doi.org/10.1086/260930
Brown, S. J., & Warner, J. B. (1980). Measuring security price performance. *Journal of Financial Economics, 8*(3), 205–258. https://doi.org/10.1016/0304-405X(80)90002-1
Brown, S. J., & Warner, J. B. (1985). Using daily stock returns: The case of event studies. *Journal of Financial Economics, 14*(1), 3–31. https://doi.org/10.1016/0304-405X(85)90042-X
Busch, T., Bauer, R., & Orlitzky, M. (2016). Sustainable development and financial markets: Old paths and new avenues. *Business & Society, 55*(3), 303–329. https://doi.org/10.1177/0007650315570701
Campbell, I., & Meyers, E. (2018). *Almost 30% of power contract off-takers have medium- to low-grade credit ratings.* S&P Global Inc.
Carlton, D. W. (1979). Contracts, price rigidity, and market equilibrium. *Journal of Political Economy, 87*(5), 1034–1062. https://doi.org/10.1086/260811
Carter, D. A., Rogers, D. A., & Simkins, B. J. (2006). Does hedging affect firm value? Evidence from the US airline industry. *Financial Management, 35*(1), 53–86. https://doi.org/10.1111/j.1755-053X.2006.tb00131.x
Chai, D., Chiah, M., & Zhong, A. (2019). Choosing factors: Australian evidence. *Pacific-Basin Finance Journal, 58*, Article 101223. https://doi.org/10.1016/j.pacfin.2019.101223
Chauhan, A. (2022). *Global corporate clean energy procurement market briefing.* IHS Markit Ltd. https://cdn.ihsmarkit.com/www/pdf/0822/Global-Corporate-Clean-Energy-Procurement-Market-Briefing-June-2022-final.pdf
Chung, Y. C. Y., Kunene, N., & Chang, H.-H. (2024). Renewable energy certificates and firm value: Empirical evidence in Taiwan. *Energy Policy, 184*, Article 113870. https://doi.org/10.1016/j.enpol.2023.113870
Cox, S., & Britten, J. (2019). The Fama-French five-factor model: Evidence from the Johannesburg Stock Exchange. *Investment Analysts Journal, 48*(3), 240–261. https://doi.org/10.1080/10293523.2019.1647982
Crispeels, P., Robertson, M., Somers, K., & Wiebes, E. (2022, April 21). *Outsprinting the energy crisis.* McKinsey & Company. https://www.mckinsey.com/capabilities/operations/our-insights/outsprinting-the-energy-crisis
Di Cesare, A. (2006). Do market-based indicators anticipate rating agencies? Evidence for international banks. *Economic Notes, 35*(1), 121–150. https://doi.org/10.1111/j.0391-5026.2006.00161.x
Dionne, G. (2013). Risk management: History, definition, and critique. *Risk Management and Insurance Review, 16*(2), 147–166. https://doi.org/10.1111/rmir.12016
Dirkx, P., & Peter, F. J. (2020). The Fama-French five-factor model plus momentum: Evidence for the German market. *Schmalenbach Business Review, 72*(4), 661–684. https://doi.org/10.1007/s41464-020-00105-y
Edge, P. (2014). *An approximation of counterparty credit risk in long term power purchase agreements (PPAs).* https://doi.org/10.2139/ssrn.2586181
Efron, B. (1992). Bootstrap methods: Another look at the Jackknife. In S. Kotz & N. L. Johnson (Eds.), *Breakthroughs in statistics* (pp. 569–593). Springer New York. https://doi.org/10.1007/978-1-4612-4380-9_41
European Commission. (2023). *Commission staff working document reform of electricity market design (SWD/2023/58 final).* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2023%3A58%3AFIN
Fama, E. F., & French, K. R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics, 33*(1), 3–56. https://doi.org/10.1016/0304-405X(93)90023-5
Fama, E. F., & French, K. R. (2006). Profitability, investment and average returns. *Journal of Financial Economics, 82*(3), 491–518. https://doi.org/10.1016/j.jfineco.2005.09.009
Fama, E. F., & French, K. R. (2008). Dissecting anomalies. *The Journal of Finance, 63*(4), 1653–1678. https://doi.org/10.1111/j.1540-6261.2008.01371.x
Fama, E. F., & French, K. R. (2015). A five-factor asset pricing model. *Journal of Financial Economics, 116*(1), 1–22. https://doi.org/10.1016/j.jfineco.2014.10.010
Foye, J. (2018). A comprehensive test of the Fama-French five-factor model in emerging markets. *Emerging Markets Review, 37*, 199–222. https://doi.org/10.1016/j.ememar.2018.09.002
Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment, 5*(4), 210–233. https://doi.org/10.1080/20430795.2015.1118917
Froot, K. A., Scharfstein, D. S., & Stein, J. C. (1993). Risk management: Coordinating corporate investment and financing policies. *The Journal of Finance, 48*(5), 1629–1658. https://doi.org/10.1111/j.1540-6261.1993.tb05123.x
Gabrielli, P., Aboutalebi, R., & Sansavini, G. (2022). Mitigating financial risk of corporate power purchase agreements via portfolio optimization. *Energy Economics, 109*, Article 105980. https://doi.org/10.1016/j.eneco.2022.105980
Gatzert, N., & Kosub, T. (2016). Risks and risk management of renewable energy projects: The case of onshore and offshore wind parks. *Renewable and Sustainable Energy Reviews, 60*, 982–998. https://doi.org/10.1016/j.rser.2016.01.103
Geyer-Klingeberg, J., Hang, M., & Rathgeber, A. (2021). Corporate financial hedging and firm value: A meta-analysis. *The European Journal of Finance, 27*(6), 461–485. https://doi.org/10.1080/1351847X.2020.1816559
Gómez-Bezares, F., Przychodzen, W., & Przychodzen, J. (2017). Bridging the gap: How sustainable development can help companies create shareholder value and improve financial performance. *Business Ethics, the Environment & Responsibility, 26*(1), 1–17. https://doi.org/10.1111/beer.12135
Griffin, J. M. (2002). Are the Fama and French factors global or country specific? *The Review of Financial Studies, 15*(3), 783–803. https://doi.org/10.1093/rfs/15.3.783
Han, S. H., Shin, Y. S., Reinhart, W., & Moore, W. T. (2009). Market segmentation effects in corporate credit rating changes: The case of emerging markets. *Journal of Financial Services Research, 35*(2), 141–166. https://doi.org/10.1007/s10693-008-0049-0

Hassan, Q., Algburi, S., Sameen, A. Z., Salman, H. M., & Jaszczur, M. (2023). A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications. *Results in Engineering, 20*, Article 101621. https://doi.org/10.1016/j.rineng.2023.101621

Henze, V. (2022, January 31). Corporate clean energy buying tops 30GW mark in record year. *Bloomberg New Energy Finance*. https://about.bnef.com/blog/corporate-clean-energy-buying-tops-30gw-mark-in-record-year/

Horváth, D., & Wang, Y.-L. (2021). The examination of Fama-French model during the Covid-19. *Finance Research Letters, 41*, Article 101848. https://doi.org/10.1016/j.frl.2020.101848

Huang, T.-L. (2019). Is the Fama and French five-factor model robust in the Chinese stock market? *Asia Pacific Management Review, 24*(3), 278–289. https://doi.org/10.1016/j.apmrv.2018.10.002

Hulshof, D., & Mulder, M. (2020). The impact of renewable energy use on firm profit. *Energy Economics, 92*, Article 104957. https://doi.org/10.1016/j.eneco.2020.104957

Hundt, S. (2023). Corporate power purchase agreements and the value of decarbonization. *International Journal of Energy Sector Management*. Advance online publication. https://doi.org/10.1108/IJESM-03-2023-0008

Hundt, S., Jahnel, J., & Horsch, A. (2021). Power purchase agreements and financing renewables: An interdependency. *The Journal of Structured Finance, 27*(1), 35–50. https://doi.org/10.3905/jsf.2020.1.119

Hundt, S., Jahnel, J., & Horsch, A. (2022). Decarbonization of the Chinese power market — Does a digital platform support energy transition? *Zeitschrift für Umweltpolitik & Umweltrecht, 45*(3), 300–331. https://online.ruw.de/suche/zfu/Decarboniza-of-the-Chin-Powe-Mark--Does-a-Digi-Pla-edc2ee46f07b1b3b21dd9877a3d7f1b7

Hundt, S., Sprungk, B., & Horsch, A. (2017). The information content of credit ratings: Evidence from European convertible bond markets. *The European Journal of Finance, 23*(14), 1414–1445. https://doi.org/10.1080/1351847X.2016.1204333

International Energy Agency (IEA). (2022). *Advancing decarbonisation through clean electricity procurement*. https://iea.blob.core.windows.net/assets/4a07d1b5-1beb-4611-874d-7acd4f21d9eb/AdvancingDecarbonisationthroughCleanElectricityProcurement.pdf

International Renewable Energy Agency (IRENA). (2018). *Corporate sourcing of renewables: Market and industry trends — REmade Index 2018*. https://www.irena.org/Publications/2018/May/Corporate-Sourcing-of-Renewable-Energy

Jin, Y., & Jorion, P. (2006). Firm value and hedging: Evidence from U.S. oil and gas producers. *The Journal of Finance, 61*(2), 893–919. https://doi.org/10.1111/j.1540-6261.2006.00858.x

Kim, S. (2019). The process model of corporate social responsibility (CSR) communication: CSR communication and its relationship with consumers' CSR knowledge, trust, and corporate reputation perception. *Journal of Business Ethics, 154*(4), 1143–1159. https://doi.org/10.1007/s10551-017-3433-6

Kolari, J. W., & Pynnonen, S. (2011). Nonparametric rank tests for event studies. *Journal of Empirical Finance, 18*(5), 953–971. https://doi.org/10.1016/j.jempfin.2011.08.003

Li, Y., & Flynn, P. C. (2004). Deregulated power prices: Comparison of volatility. *Energy Policy, 32*(14), 1591–1601. https://doi.org/10.1016/S0301-4215(03)00130-7

Lorraine, N. H. J., Collison, D. J., & Power, D. M. (2004). An analysis of the stock market impact of environmental performance information. *Accounting Forum, 28*(1), 7–26. https://doi.org/10.1016/j.accfor.2004.04.002

Marsat, S., Pijourlet, G., & Ullah, M. (2022). Does environmental performance help firms to be more resilient against environmental controversies? International evidence. *Finance Research Letters, 44*, Article 102028. https://doi.org/10.1016/j.frl.2021.102028

Mendicino, L., Menniti, D., Pinnarelli, A., & Sorrentino, N. (2019). Corporate power purchase agreement: Formulation of the related levelized cost of energy and its application to a real life case study. *Applied Energy, 253*, Article 113577. https://doi.org/10.1016/j.apenergy.2019.113577

Michalisin, M., & Stinchfield, B. (2010). Climate change strategies and firm performance: An empirical investigation of the natural resource-based view of the firm. *Journal of Business Strategies, 27*(2), 123–149. https://doi.org/10.54155/jbs.27.2.123-149

Mikkelson, W. H., & Partch, M. M. (1988). Withdrawn security offerings. *The Journal of Financial and Quantitative Analysis, 23*(2), 119–133. https://doi.org/10.2307/2330876

Mohseni Taheri, D., Nadarajah, S., & Trivella, A. (2023). *Physical vs virtual corporate power purchase agreements: Meeting renewable targets amid demand and price uncertainty*. https://doi.org/10.2139/ssrn.4520684

Mount, D. M., Netanyahu, N. S., Piatko, C. D., Silverman, R., & Wu, A. Y. (2014). On the least trimmed squares estimator. *Algorithmica, 69*(1), 148–183. https://doi.org/10.1007/s00453-012-9721-8

Nelson, J. M., Moffitt, J. S., & Affleck-Graves, J. (2005). The impact of hedging on the market value of equity. *Journal of Corporate Finance, 11*(5), 851–881. https://doi.org/10.1016/j.jcorpfin.2005.02.003

Nerlinger, M., & Utz, S. (2022). The impact of the Russia-Ukraine conflict on energy firms: A capital market perspective. *Finance Research Letters, 50*, Article 103243. https://doi.org/10.1016/j.frl.2022.103243

Nguyen-Viet, B. (2022). Understanding the influence of eco-label, and green advertising on green purchase intention: The mediating role of green brand equity. *Journal of Food Products Marketing, 28*(2), 87–103. https://doi.org/10.1080/10454446.2022.2043212

Novy-Marx, R. (2013). The other side of value: The gross profitability premium. *Journal of Financial Economics, 108*(1), 1–28. https://doi.org/10.1016/j.jfineco.2013.01.003

Park, N. K. (2004). A guide to using event study methods in multi-country settings. *Strategic Management Journal, 25*(7), 655–668. https://doi.org/10.1002/smj.399

Patell, J. M. (1976). Corporate forecasts of earnings per share and stock price behavior: Empirical test. *Journal of Accounting Research, 14*(2), 246–276. https://doi.org/10.2307/2490543

Pham, H., Ha, V., Le, H.-H., Ramiah, V., & Frino, A. (2024). The effects of polluting behaviour, dirty energy and electricity consumption on firm performance: Evidence from the recent crises. *Energy Economics, 129*, Article 107247. https://doi.org/10.1016/j.eneco.2023.107247

Pohl, C., Schüler, G., & Schiereck, D. (2023). Borrower- and lender-specific determinants in the pricing of sustainability-linked loans. *Journal of Cleaner Production, 385*, Article 135652. https://doi.org/10.1016/j.jclepro.2022.135652

Rousseeuw, P. J. (1984). Least median of squares regression. *Journal of the American Statistical Association, 79*(388), 871–880. https://doi.org/10.1080/01621459.1984.10477105

Rousseeuw, P. J., & Leroy, A. M. (1987). *Robust regression and outlier detection* (1st ed.). John Wiley & Sons. https://doi.org/10.1002/0471725382
Rousseeuw, P. J., & van Zomeren, B. C. (1990). Unmasking multivariate outliers and leverage points. *Journal of the American Statistical Association, 85*(411), 633–639. https://doi.org/10.1080/01621459.1990.10474920
Salvi, A., Petruzzella, F., & Giakoumelou, A. (2018). Green M&A deals and bidders' value creation: The role of sustainability in post-acquisition performance. *International Business Research, 11*(7), 96–105. https://doi.org/10.5539/ibr.v11n7p96
Schütze, F., & Stede, J. (2024). The EU sustainable finance taxonomy and its contribution to climate neutrality. *Journal of Sustainable Finance & Investment, 14*(1), 128–160. https://doi.org/10.1080/20430795.2021.2006129
Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3–4), 591–611. https://doi.org/10.2307/2333709
Shin, H., Ellinger, A. E., Nolan, H. H., DeCoster, T. D., & Lane, F. (2018). An assessment of the association between renewable energy utilization and firm financial performance. *Journal of Business Ethics, 151*(4), 1121–1138. https://doi.org/10.1007/s10551-016-3249-9
Simonelli, F. (2019). *Competitiveness of corporate sourcing of renewable energy: Part 2 of the study on the competitiveness of the renewable energy sector* (Final report ENER/C2/2016-501). European Commission. https://cdn.ceps.eu/wp-content/uploads/2019/09/Part-2_Competitiveness-of-corporate-sourcing-of-renewable-energy.pdf
Smith, C. W., & Stulz, R. M. (1985). The determinants of firms' hedging policies. *The Journal of Financial and Quantitative Analysis, 20*(4), 391–405. https://doi.org/10.2307/2330757
Sorokina, N., Booth, D. E., & Thornton, J. H. (2013). Robust methods in event studies: Empirical evidence and theoretical implications. *Journal of Data Science, 11*(3), 575–606. https://doi.org/10.6339/JDS.2013.11(3).1166
Tang, C., & Zhang, F. (2019). Classification, principle and pricing manner of renewable power purchase agreement. *IOP Conference Series: Earth and Environmental Science, 295*(5), Article 052054. https://doi.org/10.1088/1755-1315/295/5/052054
Templeman, L., Cotaga, O., & Reid, J. (2021). *ESG survey — What corporates and investors think.* Deutsche Bank Research. https://www.dbresearch.com/PROD/RPS_EN-PROD/PROD0000000000520951/ESG_Survey_%E2%80%93_What_corporates_and_investors_think.PDF
van Dijk, M. A. (2011). Is size dead? A review of the size effect in equity returns. *Journal of Banking & Finance, 35*(12), 3263–3274. https://doi.org/10.1016/j.jbankfin.2011.05.009
Wasilewski, M., Zabolotnyy, S., & Osiichuk, D. (2021). Characteristics and shareholder wealth effects of mergers and acquisitions involving European renewable energy companies. *Energies, 14*(21), Article 7126. https://doi.org/10.3390/en14217126
Wong, J. B., & Zhang, Q. (2022). Stock market reactions to adverse ESG disclosure via media channels. *The British Accounting Review, 54*(1), Article 101045. https://doi.org/10.1016/j.bar.2021.101045
World Business Council for Sustainable Development (WBCSD). (2020). *Cross-border renewable PPAs in Europe: An overview for corporate buyers.* https://www.wbcsd.org/resources/cross-border-renewable-ppas-in-europe/
Zeren, F., Yilmaz, T., & Belke, M. (2019). Testing the validity of Fama French five factor asset pricing model: Evidence from Turkey. *Financial Studies, 23*(2), 97–115. https://www.econstor.eu/bitstream/10419/231679/1/167051434X.pdf
Zumente, I., & Bistrova, J. (2021). ESG importance for long-term shareholder value creation: Literature vs. practice. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(2), Article 127. https://doi.org/10.3390/joitmc7020127