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Factors Affecting Return on Assets in the Renewable Energy Sector during Supply Chain Disruptions

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Abstract: Return on assets (ROA) is a critical metric in assessing a company's sustainability, especially in light of supply chain disruptions. Within the renewable energy sector, such disruptions often lead to a decline in ROA. Through the utilization of a within-between random model, this study uncovers the necessity for distinct strategies both prior to and during supply chain disruptions to maintain a high ROA. Pre-disruption, emphasis should be placed on securing additional funding for research and development (R&D) initiatives and expanding market reach. However, amid disruptions, sustaining a high ROA demands a strategic pivot. Specifically, renewable energy firms should scale back expansion efforts, redirect cash toward R&D, and exercise caution when venturing into new international markets, particularly in the absence of substantial government subsidies. Notably, this paper focuses solely on large-scale listed companies, overlooking potential innovative strategies employed by smaller-scale companies—an area ripe for future investigation. Despite this limitation, our findings offer valuable insights into enhancing sustainable performance within the renewable energy sector.

Keywords: return on assets; renewable energy; supply chain disruptions; strategies

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1. Introduction

The renewable energy sector plays a critical role in the global energy transition. Over recent years, the sector has experienced substantial growth driven by the increasing recognition of the need to address climate change, reduce carbon emissions, and achieve sustainable development goals. Governments and organizations worldwide are investing heavily in renewable energy to reduce dependency on fossil fuels, mitigate environmental impacts, and enhance energy security (IRENA 2022).

In recent years, the role of the renewable energy sector has expanded significantly. Advances in technology, reductions in costs, and supportive policies have accelerated the deployment of renewable energy sources such as solar, wind, hydro, and bioenergy. According to the International Renewable Energy Agency (IRENA), renewable energy capacity has been increasing at an average annual rate of over 8% in the last decade (IRENA 2022). This growth reflects a shift from renewable energy being a supplementary energy source to becoming a central component of the global energy mix.

Renewable energy plays varying roles across different countries. The EU has been a global leader in renewable energy adoption, with countries like Germany, Denmark, and Spain achieving high penetration rates of renewables in their energy mix. The EU's Green Deal and targets for carbon neutrality by 2050 further underscore the sector's importance (Fetting 2020).

As the world's largest renewable energy market, China has made significant investments in solar and wind power, aiming to peak carbon emissions before 2030 and achieve carbon neutrality by 2060 (Zhang and Chen 2022).

In the U.S., renewable energy sources are rapidly gaining importance due to federal and state policies, corporate commitments, and the declining costs of renewables. As the world's largest economy, the U.S. renewable energy sector wields significant influence over the global environmental industry.

Despite having vast oil reserves, countries like Saudi Arabia and the United Arab Emirates are increasingly investing in renewable energy to diversify their economies and reduce reliance on fossil fuels. However, they still rely on fossil fuels (Lee 2021).

The advantages of renewable energy are manifold: Firstly, it reduces greenhouse gas emissions and air pollution, contributing to improved public health and environmental sustainability. Secondly, diversification of energy sources enhances energy security by reducing dependency on imported fuels. Lastly, the renewable energy sector not only creates jobs but also stimulates technological innovation, ultimately driving economic growth.

The disadvantages of renewable energy include the intermittent nature of sources such as solar and wind, which necessitate sophisticated grid management and energy storage solutions to maintain reliability. Although costs are decreasing, renewable energy projects often require a substantial initial investment, posing financial challenges. Additionally, the renewable energy sector is vulnerable to supply chain disruptions, which can hinder the availability of critical components and materials, thereby affecting project timelines and financial performance.

The renewable energy sector has faced significant challenges in its supply chain since 2020, prompting a comprehensive analysis to uncover their origins. Similar to other industries, the renewable energy sector is subject to cyclical patterns influenced by governmental policies, investment patterns, and technological progress. Despite its promising long-term trajectory, the industry remains susceptible to fluctuations driven by various internal and external factors.

Supply chain disruptions within the renewable energy sector encompass interruptions in the flow of crucial materials, components, or services essential for the manufacturing and distribution of renewable energy technologies such as solar panels, wind turbines, and batteries. These disruptions, arising from natural calamities like earthquakes, geopolitical tensions, economic downturns, regulatory shifts, or unforeseen events such as the COVID-19 pandemic, often result in delays, increased expenses, and challenges in meeting market demands.

Among natural calamities, geopolitical tensions, economic downturns, regulatory shifts, and pandemic-related disruptions, all are ultimately critical due to their potential to cause significant project delays, increase costs, and impact the availability of essential components. However, pandemic-related disruptions, although rare, have more significant impacts than other disruptions such as labor shortages and transportation issues. These disruptions deserve research attention to enhance resilience, support technological advancement, and ensure the sector's continued growth and contribution to global environmental and economic goals. Studying supply chain disruptions helps in developing strategies for resilience and better strategic planning. Understanding the causes and impacts of disruptions enables companies and policymakers to implement countermeasures, diversify supply sources, and develop contingency plans to mitigate risks.

Extreme climate events are increasingly likely, leading to frequent disruptions that can cause significant losses (Pathak et al. 2022). Natural calamities have impacts similar to pandemic-related disruptions. Studying pandemic-related disruptions can also help identify effective countermeasures for natural calamities.

This study focuses on the determinants impacting return on assets (ROA) within the renewable energy sector during episodes of supply chain disruptions. ROA serves as a pivotal metric for evaluating a company's sustainability and competitive standing by assessing efficient asset utilization. While strategies for enhancing ROA during growth periods are well-established, navigating ROA during supply chain disruptions requires further examination.

The remainder of this article is organized as follows: Section 2 delves into the literature review. Section 3 provides background information and outlines the hypotheses. Section 4 details the selection of variables and model specifications. Section 5 elucidates the findings. Section 6 discusses the findings and concludes.

2. The Literature on the Factors Affecting ROA in the Renewable Energy Sector during Supply Chain Disruptions

The renewable energy sector, characterized by its unique industry dynamics, is particularly vulnerable to supply chain disruptions. This paper endeavors to investigate strategies that enable renewable energy companies to not only navigate but also flourish amidst such disruptions.

Sustainable energy encompasses renewable resources capable of fulfilling both present-day requirements and the needs of future generations (Askarany et al. 2021; Prindle et al. 2007; Wang and Liu 2021; Sweidan 2021; Shorabeh et al. 2021; Petrusic and Janjic 2021; Ivanovski et al. 2021). Aligned with the aforementioned descriptions, sustainable energy encompasses a spectrum of renewable resources, encompassing solar, bio, wind, hydro, wave, green, and geothermal energies, alongside technologies aimed at enhancing energy efficiency (Prindle et al. 2007; Guo et al. 2021; Yano and Cossu 2019; Stucki 2019; Miremadi et al. 2019; Manolis et al. 2019; Fadly and Fontes 2019; Ali et al. 2019). Often described as domestic resources generating minimal to no greenhouse gases or pollutants (Büyüközkan and Güleryüz 2016), renewable energy sources contribute significantly to reducing CO_2 emissions and mitigating climate change (Lu et al. 2021; Bowden and Payne 2009; Payne 2009).

ROA emerges as a pivotal metric for evaluating firm performance, as indicated by previous research (Athanasoglou et al. 2008; Tan 2016; Yudaruddin 2023). In this context, Seissian et al. (2018) and AlGhusin (2015) examined the impact of various financial indicators on the performance of listed companies, including credit rating, current ratio, leverage ratio, average tax rate, growth, firm size, and fixed assets/total assets ratio. Homapour et al. (2022) utilized the total debts to total assets ratio as a proxy for leverage ratio, a method adopted in our study.

Susilowati et al. (2023) investigated the combined effect of a COVID-19 dummy variable (covid1, which is 1 for 2020 and 0 otherwise) and cash holding on the ROA of the alternative fuels sector. They observed a significant negative effect. However, it is important to note that the alternative fuels sector differs from the renewable energy sector. While the alternative fuels sector focuses on substitutes for gasoline and diesel in transportation, including non-renewable alternatives like natural gas and propane, natural gas fuel companies typically require more assets than renewable energy companies due to the extensive infrastructure needed for extraction, processing, and transportation. Consequently, the behavior of the alternative fuels sector may differ from that of the renewable energy sector.

While these studies do not specifically focus on the renewable energy sector, they provide valuable insights into potential factors influencing ROA that we aim to investigate.

We also include research and development (R&D) expenses in our model, recognizing their significant impact on the performance of renewable energy companies. Apergis and Payne (2010a, 2010b) and Luqman et al. (2019) argue that technological advancements have driven down the costs associated with investing in renewable energy installations, thereby fostering increased utilization of renewable energy sources (Lu et al. 2021). We will examine the relationship between R&D activities and ROA within renewable energy companies.

Government policies represent another influential factor shaping the performance of renewable energy companies. Policies that encourage renewable energy investment, such as relaxed credit conditions and tax incentives, serve as incentives. Governments globally have implemented certification and portfolio standards to stimulate the adoption of renewable energy sources (Apergis and Payne 2012; Asiedu et al. 2021). The impact of government policies may take several years to manifest. We will not incorporate government policy variables into our current analysis.

Before we talk about the strategies used during disruptions, let us discuss the cause of disruptions. Sgarbossa et al. (2023) argue that the development of a hydrogen supply chain

(HSC) hinges on the level of hydrogen adoption, market development, and the maturity of associated technologies, all of which are marked by high uncertainties. These uncertainties lead to cyclical fluctuations, sometimes disruptions.

Several cross-country analyses have highlighted the significant negative impact of COVID-19 on firm performance (Hu and Zhang 2021; Zheng 2022; Ahmad et al. 2021; Golubeva 2021; Atayah et al. 2022; Toumi et al. 2023; Guérin and Suntheim 2021). Similar patterns have been observed in countries like the U.S. (Yong and Laing 2021; Huang et al. 2021; Neukirchen et al. 2022; Chebbi et al. 2021; Kumar and Zbib 2022; Hsu and Liao 2022; Didier et al. 2021; Song et al. 2021; Ke 2022).

Renewable energy projects have not been immune to disruptions, as noted by Olabi et al. (2022). They highlighted hindrances such as inadequate funding allocation and supply chain disruptions for equipment and components, which have been exacerbated by lockdown measures.

This study enhances prior studies concentrated on assessing the effects of COVID-19 on energy sector company performance (Szczygielski et al. 2022; Li et al. 2022; Akyildirim et al. 2022; Ghosh 2022; Lu and Khan 2023; Clemente-Almendros et al. 2022). Learning from Alsamhi et al. (2022) and Shen et al. (2020), who explored how company characteristics influenced company performance amidst COVID-19, our study examined how company characteristics influenced the performance of renewable energy companies during supply chain disruptions.

Can supply chain disruptions in the renewable energy sector be prevented? Labaran and Masood (2023) stated that Industry 4.0 technology has the potential to enhance green supply chain management within the renewable energy sector. Leveraging various Industry 4.0 technologies such as blockchain, Internet of Things (IoT), Big Data, and Artificial Intelligence (AI) can enable efficient supply chain management through real-time data and intelligent systems. The European Commission coined the term "Industry 5.0" (European Commission 2021). Industry 5.0 integrates resilient, sustainable, and human-centric approaches in both organization and technology, surpassing the purely technological focus of Industry 4.0 (Ivanov 2023). However, while cyclical fluctuations in the renewable energy industry cannot be entirely eliminated, they can be mitigated. Thus, strategies to thrive during supply chain disruptions remain crucial for both entrepreneurs and government entities, and this research aims to tackle such challenges.

For example, the pandemic has significantly impacted both ongoing and operational solar projects due to supply chain and construction disruptions. The rooftop solar sector has been hit hardest, as it mainly comprises relatively smaller firms lacking the financial capacity to withstand the losses (Deshwal et al. 2021). Throughout the COVID-19 pandemic, almost 75% of solar energy system companies in Africa remained operational, but during the lockdown, the majority anticipated facing insolvency (Olabi et al. 2022). Monitoring the financial ratios of renewable energy firms is essential to ensure their long-term viability.

Previous research has not specifically examined how financial ratios affect ROA in the context of the renewable energy sector and supply chain disruptions. This study aims to investigate these financial ratios and their impact on ROA amidst supply chain challenges in this sector. By doing so, we aim to contribute valuable insights to the existing body of knowledge in this field.

3. Background and Hypotheses

In March 2020, over 100 countries implemented varying degrees of lockdown measures in response to the global pandemic (Johns Hopkins University 2022). This led to substantial disruptions in the clean energy sector, with projects being halted for extended periods, ranging from months to years. These disruptions affected every stage of the supply chain, including sourcing, processing, production, assembly, transportation, and distribution. Effective management during such disruptions has the potential to positively impact or increase ROA. And it is our responsibility to unveil this correlation.

Supply chain disruptions pose inherent risks that can significantly impact firm profitability. Prior to these disruptions, certain listed renewable energy companies were found to have surplus current assets. However, an excess of liquidity is often linked to decreased profitability. Additionally, adopting expansive strategies during disruptions can heighten risk exposure. On the other hand, embracing innovative strategies has the potential to enhance a company's competitive advantage. Building upon these observations, we propose Hypotheses 1–4:

Hypothesis 1. *Current ratio is negatively related to ROA during supply chain disruptions (between-company correlation).*

Hypothesis 2. *Fixed assets/total assets ratio is negatively related to ROA during supply chain disruptions (between-company correlation).*

Hypothesis 3. *Growth is negatively related to ROA during supply chain disruptions (between-company correlation).*

Hypothesis 4. *R&D expense is positively related to ROA during supply chain disruptions (between-company correlation).*

4. Variable Selection and Model Specification

4.1. Measures

4.1.1. Current Ratio

The current ratio (currentratio), often used as a proxy for liquidity, is calculated by dividing a company's current assets by its current liabilities. During supply chain disruptions, many companies face financial constraints. Accumulating excess cash during this period could result in underinvestment in critical areas such as R&D or supply chain diversification. Such underinvestment is detrimental to overall business development. We expect that the current ratio has a negative effect on ROA.

4.1.2. Fixed Assets/Total Assets Ratio

The fixed assets/total assets ratio (fixedassetstototalassets), known as the fixed asset ratio, is calculated by dividing the value of fixed assets by the total value of all assets. During supply chain disruptions, companies with a higher fixed assets/total assets ratio might face challenges in liquidating fixed assets for cash flow needs. Additionally, the expansion strategy carries higher risks compared to pre-disruption conditions, so we expect that the fixed assets/total assets ratio has a negative effect on ROA.

4.1.3. Growth

Growth, serving as a measure of a company's expansion, is determined by the variation in total assets over consecutive two-year periods. During supply chain disruptions, the expansion strategy carries higher risks compared to pre-disruption conditions, so we expect growth to have a negative effect on ROA.

4.1.4. R&D Expense

"R&D expense" refers to the expenditure recorded on a company's income statement for research and development activities, reflecting its investment in research capital. During supply chain disruptions, companies with significant R&D investments may be better positioned to innovate and adapt. Given the capital-intensive nature of the renewable energy sector, we anticipate that higher R&D expenses will positively influence ROA.

4.1.5. Control Variables

In order to assess the determinants of ROA within the renewable energy sector, this analysis accounts for the impact of various factors, including credit rating, debt-to-assets ratio, average tax rate, total assets, company age, and international business presence on ROA.

Credit rating (creditrating) is quantified as interest expenses divided by the average outstanding debt balance. During supply chain disruptions, companies with better access to financing and more favorable borrowing terms can navigate disruptions more effectively. A higher credit rating indicates a greater interest burden and reduced solvency. Consequently, we anticipate that credit rating will negatively impact ROA.

The debt-to-assets ratio (debttoassets), used as a proxy for leverage, is determined by dividing total debts by total assets. In the short term, higher leverage enhances companies' capacity to invest in R&D. However, during supply chain disruptions, higher leverage increases the risk of default. We anticipate a negative relationship between the debt-to-assets ratio and ROA across companies during supply chain disruptions. However, we anticipate that a within-company change in the debt-to-assets ratio will positively correlate with a within-companies change in ROA, both before and during supply chain disruptions.

The average tax rate (averagetaxrate) is determined by dividing the total tax expense by the company's pre-tax income. Tax policies or changes during supply chain disruptions can affect cash flow and profitability. Given that higher tax expenses tend to reduce ROA, we expect the average tax rate to exert a negative influence on ROA.

Total assets (totalassets) can positively impact ROA if efficiently utilized but can have a negative effect otherwise. In the renewable energy sector, during 2017 and 2018, inventory increased substantially due to enhanced productivity. Consequently, we anticipate that total assets will have a negative effect on ROA prior to supply chain disruptions.

The company age (age) equals the year of the data minus the start year. Old renewable energy companies are more likely than new ones to encounter challenges related to outdated technology and fixed assets. These challenges are more obvious during supply chain disruptions. Thus, we anticipate a negative correlation between company age and ROA across renewable energy companies during supply chain disruptions.

International business presence (internationalbusiness) is a binary variable, taking the value of one when the company engages in international business and zero otherwise. Due to the heightened unseen risks in international markets during supply chain disruptions compared to pre-disruption periods, we expect that international business presence will negatively impact ROA during supply chain crises.

The dependent variable is ROA. To mitigate multicollinearity, certain control variables were excluded from the regression model.

4.2. Within-Between Random Models

We employed a within-between random model to account for company-specific effects, as this model can differentiate between- and within-company variance. This model enables separate analysis of the impact of financial ratios on ROA at two distinct levels: how differences between companies (between-company) and changes within the same company over time (within-company) impact ROA. The longitudinal nature of the data, collected from companies over two to three years, naturally creates a multilevel structure where repeated measures (within-company) are nested within individual companies (between-company). The within-between random model appropriately handles this nested structure, resulting in a more accurate analysis of the data. The within-between random model preserves the between effect, offering valuable insights (Bell et al. 2019). Bell and Jones (2015) demonstrated that a primary concern with random effects models is the potential correlation between covariates and residuals, a challenge effectively addressed by the within-between random effects models. The model can be represented as follows:

$$y_{it} = \beta_0 + \beta_1(x_{it} - \overline{x}_i) + \beta_2 h_i + \beta_3 \overline{x}_i + \mu_i + \varepsilon_{it} \quad (1)$$

In Equation (1), i represents level 2 (companies) and t represents level 1 (occasions). y_{it} serves as the dependent variable in the model. x_{it} represents a level 1 variable, exhibiting variation both between and within companies, and the variable h_i represents a level 2 factor that exhibits variation solely among different companies. μ_i represents the level 2 error component, whereas ε_{it} denotes the level 1 error component or stochastic disturbance term. $\bar{x}_i = n_i^{-1}\sum_{t=1}^{n_i} x_{it}$. β_1 is the average within-effect of x_{it}. β_3 represents the average between-effect of x_{it}. β_2 indicates the influence of the time-invariant variable h_i. It is a between effect. In the above equation, $ROA_{i,t}$ serves as the dependent variable, indicating ROA for a company i in year t. $Internationalbusiness_i$ is the level 2 variable. It is a dummy variable that equals one when the company engages in international business and zero otherwise. The remaining variables are considered as level 1 variables. These encompass credit rating, current ratio, average tax rate, total assets, fixed assets/total assets ratio, changes in total assets over consecutive two-year periods as a proxy for company growth, the ratio of total debts to total assets, R&D expense, debt-to-assets ratio, and age. Due to multicollinearity, it is not feasible to include all independent variables simultaneously in a single equation. We employed the Breusch and Pagan Lagrange multiplier test to discern the most suitable approach, thereby confirming the presence of the panel effect. The model is estimated using Stata.

4.3. Data Sources and Statistical Summaries

This study utilized panel data encompassing 17 listed companies in the U.S. stock market over two distinct time intervals, 2017–2019 and 2020–2021. The focus is on comprehensively evaluating the determinants impacting ROA within the renewable energy sector amidst supply chain disruptions that occurred in 2020. I do not include the data for 2022 here. That is because the Inflation Reduction Act by Biden in 2022 may contribute to the ROA of companies in the renewable energy sector in the U.S., which is another topic and needs more years to be proved.

The sample comprises listed companies within the renewable energy sector. Data sources include websites dedicated to solar and wind energy companies in the United States (Accessed on 7 December 2023: https://en.wikipedia.org/wiki/Category:Solar_energy_companies_of_the_United_States, and https://en.wikipedia.org/wiki/Category:Wind_power_companies_of_the_United_States), as well as a section for U.S. stocks within the renewable energy sector from a finance website (Accessed on 7 December 2023: https://finance.sina.com.cn/stock/usstock/sector.shtml#c109m). However, exceptions exist. E.ON, a German multinational corporation headquartered in Germany, is included in our study based on its membership in the Dow Jones Global Titans 50 index and its presence on the list from Wikipedia.org. Similarly, JinkoSolar Holding Co., Ltd., a Chinese company, is encompassed within the sample despite its origin, as it operates factories within the U.S. and has issued stocks in the U.S. within the renewable energy sector. Companies with incomplete datasets spanning the period from 2017 to 2021 are excluded.

There are eight solar companies, one wind company, four bioenergy companies, one ocean wave energy company, two solar equipment companies, and one clean energy utility company in my sample. All data were sourced from Bloomberg. Table 1 presents descriptive statistics for the primary indicators of 17 companies during 2017–2019. Table 2 presents descriptive statistics for the primary indicators of 17 companies during 2020–2021. Table 3 presents descriptive statistics for the primary indicators of companies with positive ROA from 2017 to 2019. Table 4 presents descriptive statistics for the primary indicators of companies with positive ROA from 2020 to 2021.

Comparing Tables 1 and 2 reveals shifts in the characteristics of the 17 listed companies between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, the mean ROA increases; the mean creditrating decreases; the mean currentratio increases; the mean debttoassets decreases, suggesting a decline in leverage; the mean averagetaxrate increases; the mean value of growth increases; and the mean R&D expense increases. These findings indicate an overall improvement in the performance of listed companies during supply chain disruptions compared to the period preceding them. Why did the performance of listed companies improve during supply chain disruptions compared to the preceding period? This phenomenon may be attributed to the implementation of key strategies such as technological innovation, partnerships, and specialization. For example, in November 2019, SunPower Corp. (SPWR), a major U.S. solar panel manufacturer, announced it was exiting its manufacturing operations to concentrate on installing rooftop solar systems. In 2020, its ROA was 24.882, compared to 0.9795 in 2019.

Table 1. Descriptive statistics for 17 companies from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
return on assets (ROA) (%)	51	−14.9505	47.2038	−227.8936	30.6028
creditrating (100%)	51	0.046	0.0638	0	0.2966
currentratio (100%)	51	2.3952	2.7196	0.0191	14.7346
debttoassets (%)	51	99.9132	142.8191	0	545.6697
averagetaxrate (100%)	51	−0.0408	0.6502	−3.5696	1.8405
growth (%)	51	12.2095	29.8262	−41.6021	109.8103
totalassets (millions of USD)	51	13,668.2	30,423.07	5.6335	117,691
R&D (millions of USD)	51	138.7538	460.0295	0	2054

Table 2. Descriptive statistics for 17 companies from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	34	−1.7055	19.2546	−64.8947	24.882
creditrating (100%)	34	0.0301	0.0264	0	0.1203
currentratio (100%)	34	3.3302	3.4186	0.0852	17.9887
debttoassets (%)	34	82.6217	127.6031	0	523.1566
averagetaxrate (100%)	34	0.0569	0.164	−0.366	0.5496
fixedassetstototalassets (100%)	34	0.335	0.2266	0.0167	0.7668
growth (%)	34	40.5519	94.9805	−26.2877	538.0337
R&D (millions of USD)	34	171.6326	558.4651	0	2485
age (Year)	34	28.7941	21.6638	8	96
internationalbusiness	34	0.8235	0.387	0	1

Table 3. Descriptive statistics for 6 companies with positive ROA from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	18	8.1337	6.2705	0.5179	20.7067
creditrating (100%)	18	0.0178	0.0096	0	0.0318
currentratio (100%)	18	3.2889	4.0083	0.364	14.7346
debttoassets (%)	18	115.5738	184.2106	0	517.8426
averagetaxrate (100%)	18	−0.0378	0.4466	−1.5713	0.3089
growth (%)	18	19.597	23.8918	−10.3241	71.4831
totalassets (millions of USD)	18	35,206.7	44,199.81	471.393	117,691
R&D (millions of USD)	18	352.5349	738.8315	0	2054

Table 4. Descriptive statistics for 6 companies with positive ROA from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	12	6.5204	7.5231	0.4559	24.4427
creditrating (100%)	12	0.013	0.0086	0	0.0246
currentratio (100%)	12	2.7381	2.5851	0.4745	8.4182
debttoassets (%)	12	119.1005	189.741	0	523.1566
averagetaxrate (100%)	12	0.148	0.1353	−0.1296	0.3994
fixedassetstototalassets (100%)	12	0.3187	0.2126	0.083	0.7232
growth (%)	12	19.3232	19.2765	−4.2272	63.0583
R&D (millions of USD)	12	447.4912	897.2676	0	2485
age (Year)	12	39.8333	29.9843	14	96
internationalbusiness	12	0.6667	0.4924	0	1

Comparing Tables 3 and 4 reveals shifts in the characteristics of six listed companies with positive ROA between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, the mean ROA decreases; the mean creditrating decreases; the mean currentratio decreases; the mean debttoassets increases, suggesting an increase in leverage; the mean averagetaxrate increases; the mean value of growth decreases; and the mean value of R&D increases. These findings suggest that during supply chain disruptions, the listed companies with positive ROA tend to reduce their growth rate while allocating relatively more cash and borrowing additional funds to invest in R&D compared to the period prior to the disruptions.

Table 5 presents descriptive statistics for the primary indicators of eight solar companies from 2017 to 2019. Table 6 presents descriptive statistics for eight solar companies from 2020 to 2021. Table 7 presents descriptive statistics for one wind company from 2017 to 2019. Table 8 presents descriptive statistics for one wind company from 2020 to 2021. Table 9 presents descriptive statistics for four bioenergy companies from 2017 to 2019. Table 10 presents descriptive statistics for four bioenergy companies from 2020 to 2021. Table 11 presents descriptive statistics for one ocean wave energy company from 2017 to 2019. Table 12 presents descriptive statistics for one ocean wave energy company from 2020 to 2021.

Table 5. Descriptive statistics for 8 solar companies from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	24	−21.5695	61.7446	−227.8936	30.6028
creditrating (100%)	24	0.0633	0.088	0.0089	0.2966
currentratio (100%)	24	1.7368	1.4112	0.0191	5.8941
debttoassets (%)	24	166.922	186.5736	25.7237	545.6697
averagetaxrate (100%)	24	0.1161	0.4594	−0.7883	1.8405
growth (%)	24	20.0812	36.7947	−41.6021	109.8103
totalassets (millions of USD)	24	2957.588	2580.309	5.6335	7515.689
R&D (millions of USD)	24	44.3306	35.9217	0	121.351

Table 6. Descriptive statistics for 8 solar companies from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	16	1.5219	18.706	−59.3484	24.882
creditrating (100%)	16	0.0342	0.0301	0.0031	0.1203
currentratio (100%)	16	2.198	1.1923	0.0852	4.3903
debttoassets (%)	16	138.6044	169.8658	19.6149	523.1566
averagetaxrate (100%)	16	0.0537	0.2077	−0.366	0.5496
fixedassetstototalassets (100%)	16	0.3381	0.2396	0.0419	0.7668
growth (%)	16	38.4925	42.4052	−24.1924	147.711
R&D (millions of USD)	16	59.4345	63.8585	0	219.633
age (Year)	16	17.25	7.912	8	36
internationalbusiness	16	0.875	0.3416	0	1

Comparing Tables 5 and 6 reveals shifts in the characteristics of the listed solar companies between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, the mean ROA increases; the mean creditrating decreases; the mean currentratio increases; the mean debttoassets decreases, suggesting a decline in leverage; the mean averagetaxrate decreases; the mean value of growth increases; and the mean R&D expense increases. These findings indicate an overall improvement in the performance of listed solar companies during supply chain disruptions compared to the period preceding them. Why did the performance of listed solar companies improve during supply chain disruptions compared to the preceding period? This phenomenon may be attributed to the implementation of key strategies such as technological innovation, partnerships, and specialization.

Table 7. Descriptive statistics for 1 wind company from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	3	5.2376	1.6442	3.4048	6.5832
creditrating (100%)	3	0.0258	0.0052	0.0223	0.0318
currentratio (100%)	3	0.5125	0.1387	0.364	0.6387
debttoassets (%)	3	0	0	0	0
averagetaxrate (100%)	3	0.0632	0.1839	−0.1415	0.2144
growth (%)	3	9.4014	3.8447	5.8583	13.4896
totalassets (millions of USD)	3	106,452	10,147.43	97,963	117,691
R&D (millions of USD)	3	0	0	0	0

Table 8. Descriptive statistics for 1 wind company from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	2	2.5199	0.1989	2.3792	2.6605
creditrating (100%)	2	0.0194	0.0073	0.0143	0.0246
currentratio (100%)	2	0.5036	0.0411	0.4745	0.5327
debttoassets (%)	2	0	0	0	0
averagetaxrate (100%)	2	0.0639	0.0646	0.0182	0.1096
fixedassetstototalassets (100%)	2	0.716	0.0101	0.7089	0.7232
growth (%)	2	9.4254	1.3216	8.4909	10.36
R&D (millions of USD)	2	0	0	0	0
age (Year)	2	95.5	0.7071	95	96
internationalbusiness	2	0	0	0	0

Comparing Tables 7 and 8 reveals shifts in the characteristics of listed wind companies between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, we observe a decrease in the mean ROA, a decrease in the mean creditrating, a decrease in the mean currentratio, and an increase in the mean value of growth. These findings suggest an overall decline in the performance of listed wind companies during supply chain disruptions compared to the preceding period. The deterioration in performance may be attributed to an expanding strategy during supply chain disruptions.

Table 9. Descriptive statistics for 4 bioenergy companies from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	12	−1.9676	7.0242	−13.9805	8.5125
creditrating (100%)	12	0.0376	0.0239	0	0.0617
currentratio (100%)	12	4.0685	4.6529	0.728	14.7346
debttoassets (%)	12	37.273	20.6695	5.5414	62.9311
averagetaxrate (100%)	12	−0.4874	1.0852	−3.5696	0.0608
growth (%)	12	−4.0645	11.6111	−23.3806	11.1579
totalassets (millions of USD)	12	1034.243	766.7035	471.393	2784.65
R&D (millions of USD)	12	0	0	0	0

Table 10. Descriptive statistics for 4 bioenergy companies from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	8	−0.6302	7.3928	−11.1412	10.1707
creditrating (100%)	8	0.033	0.027	0	0.0722
currentratio (100%)	8	3.9193	2.4127	1.4194	8.4182
debttoassets (%)	8	29.3283	15.7551	8.7958	50.8103
averagetaxrate (100%)	8	0.019	0.1054	−0.1296	0.2509
fixedassetstototalassets (100%)	8	0.4192	0.0984	0.2703	0.5469
growth (%)	8	5.7212	20.981	−22.1515	36.7871
R&D (millions of USD)	8	0	0	0	0
age (Year)	8	23.5	10.5695	16	41
internationalbusiness	8	0.75	0.4629	0	1

Comparing Tables 9 and 10 reveals shifts in the characteristics of listed bioenergy companies between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, we observe an increase in the mean ROA, a decrease in the mean creditrating, a decrease in the mean currentratio, and an increase in the mean value of growth. These findings suggest an overall improvement in the performance of listed bioenergy companies during supply chain disruptions compared to the preceding period. Bioenergy production primarily relies on organic materials (biomass) which can often be sourced locally or regionally. This reduces dependency on international supply chains and mitigates the impact of global supply chain disruptions. The development and maintenance of bioenergy facilities may require less specialized and high-tech equipment compared to wind and solar energy systems. This could mean lower reliance on global supply chains for critical components.

Table 11. Descriptive statistics for 1 ocean wave energy company from 2017 to 2019.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	3	−84.0811	8.7505	−92.8901	−75.3902
creditrating (100%)	3	0	0	0	0
currentratio (100%)	3	4.2892	2.627	2.1173	7.2091
debttoassets (%)	3	29.1815	15.9741	14.1076	45.9248
averagetaxrate (100%)	3	0	0	0	0
growth (%)	3	22.5205	22.4094	−2.6867	40.1866
totalassets (millions of USD)	3	14.1867	4.1469	10.073	18.366
R&D (millions of USD)	3	4.7777	0.397	4.32	5.029

Table 12. Descriptive statistics for 1 ocean wave energy company from 2020 to 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA (%)	2	−47.2199	24.9959	−64.8947	−29.5451
creditrating (100%)	2	0	0	0	0
currentratio (100%)	2	12.0577	8.3877	6.1267	17.9887
debttoassets (%)	2	14.6666	11.0671	6.8409	22.4922
averagetaxrate (100%)	2	0	0	0	0
fixedassetstototalassets (100%)	2	0.0698	0.0751	0.0167	0.1229
growth (%)	2	255.873	399.0355	−26.2877	538.0337
R&D (millions of USD)	2	4.5455	0.285	4.344	4.747
age (Year)	2	36.5	0.7071	36	37
internationalbusiness	2	1	0	1	1

Comparing Tables 11 and 12 reveals shifts in the characteristics of listed ocean wave energy companies between the periods of 2017–2019 and 2020–2021. Compared to the former period, during the latter period, we observe an increase in the mean ROA, an improvement in the mean currentratio, a decrease in the mean debttoassets, an increase in the mean value of growth, and a decline in the mean R&D expense. These findings suggest an overall improvement in the performance of listed ocean wave energy companies during supply chain disruptions compared to the preceding period. The improvement in performance may be attributed to the adoption of new technology. Notably, Ocean Power Technologies Inc. reported an increase in intangible assets by USD 0.274 million in 2021. Ocean wave energy technology is less mature compared to solar and wind technologies; many ocean wave energy systems are still in experimental or early commercial stages. The harsh marine environment poses unique challenges, necessitating extensive testing and longer R&D cycles to ensure durability, reliability, and efficiency. The intangible assets recorded for 2021 are based on R&D expenses from previous years.

Tables 13 and 14 present the correlation matrix and coefficients for the variables employed. In this study, I apply a threshold of 0.8, as suggested by Kennedy (2008), to detect multicollinearity based on pairwise correlation coefficients.

Table 13. Correlation matrix for full sample data (2017–2019).

Variables	ROA	creditrating	currentratio	debttoassets	averagetaxrate	growth	totalassets	R&D
ROA	1							
creditrating	−0.748	1						
currentratio	0.166	−0.365	1					
debttoassets	−0.419	0.548	−0.328	1				
averagetaxrate	−0.039	−0.025	−0.201	0.067	1			
growth	0.323	−0.299	0.025	−0.095	0.039	1		
totalassets	0.194	−0.145	−0.217	−0.167	0.087	0.076	1	
R&D	0.187	−0.112	0.027	−0.071	0.111	−0.003	0.036	1

Table 14. Correlation matrix for full sample data (2020–2021).

Variables	ROA	creditrating	currentratio	debttoassets	averagetaxrate	fixedassetstototalassets
ROA	1					
creditrating	0.043	1				
currentratio	−0.358	−0.366	1			
debttoassets	0.125	0.231	−0.317	1		
averagetaxrate	0.110	−0.236	−0.172	0.272	1	
fixedassetstototalassets	0.074	0.454	−0.462	0.065	−0.14	1
growth	−0.268	−0.083	0.692	−0.060	−0.132	−0.241
totalassets	0.138	−0.187	−0.319	−0.113	0.236	0.338
R&D	0.325	−0.132	−0.051	−0.048	0.120	−0.309
age	0.023	−0.264	0.131	−0.305	0.102	−0.015
internationalbusiness	−0.097	0.177	0.021	0.228	0.044	−0.414
Variables	growth	totalassets	R&D	age	internationalbusiness	
growth	1					
totalassets	−0.117	1				
R&D	−0.069	0.030	1			
age	−0.021	0.534	0.262	1		
internationalbusiness	0.043	−0.346	0.138	−0.456	1	

5. Empirical Results

Table 15 presents the estimation results based on panel data from 17 listed companies for the period 2017–2019 in Model 1. The dependent variable is ROA. The independent variables are credit rating, current ratio, debt-to-assets ratio, average tax rate, growth, total assets, and R&D expense. Table 15 also presents the estimation results based on panel data from 17 listed companies for the period 2020–2021 in Model 2. The dependent variable is ROA. The independent variables are credit rating, current ratio, debt-to-assets ratio, average tax rate, fixed assets/total assets ratio, growth, R&D expense, company age, and international business presence.

Table 15. Results with panel data from 2017 to 2019 and from 2020 to 2021.

	M1	**M2**
	(2017–2019)	**(2020–2021)**
intercept	17.948(11.757)	44.159(4.881) *
creditrating		
Between	−568.237(75.142) *	−182.521(36.189) *
Within	−9.366(554.515)	−186.144(154.317)
currentratio		
Between	−3.663(2.462)	−3.035(0.442) *
Within	3.166(1.156) *	1.114(1.485)
debttoassets		
Between	−0.022(0.024)	−0.009(0.005) ***
Within	0.281(0.028) *	0.361(0.063) *

Table 15. *Cont.*

	M1	M2
	(2017–2019)	(2020–2021)
averagetaxrate		
Between	−16.186(9.738) ***	−27.007(7.626) *
Within	−4.315(2.787)	−12.562(22.258)
fixedassetstototalassets		
Between		−30.33(6.719) *
Within		26.317(54.522)
growth		
Between	0.08(0.131)	−0.143(0.017) *
Within	0.357(0.082) *	0.051(0.033)
totalassets		
Between	0.000(0.000)	
Within	−0.001(0.000) **	
R&D		
Between	0.013(0.007) **	0.007(0.001) *
Within	0.015(0.026)	0.018(0.023)
age		
Between		−0.131(0.036) *
Within		0.187(3.22)
internationalbusiness		−11.482(3.179) *
R^2 (between-company level)	0.716	0.968
R^2 (within-company level)	0.408	0.864
Total Observations	51	34
Total N	17	17

Note: Unstandardized regression coefficients, accompanied by their standard errors in parentheses, are presented. Within-between random models. Between-effects refer to the correlation between inter-company disparities in the independent variable and dependent variable, while within-effects denote the impact of within-company change in the independent variable from time t1 to t2 on within-company change in the dependent variable during the same period. Significance levels are denoted as follows: * ($p < 0.01$), ** ($p < 0.05$), and *** ($p < 0.10$).

In Model 1 (M1), approximately 71.6% of the variability in ROA can be attributed to inter-company differences, while 40.8% of the variability in ROA arises from variations within the company over time. Hence, the model effectively accounts for inter-company variability. In Model 2 (M2), around 96.8% of the variability in ROA is attributable to inter-company variations and 86.4% of the variability in ROA stems from variations within the company over time. Hypothesis 1 postulated a negative between-company relationship of the current ratio and ROA during supply chain disruptions. The difference between companies in the current ratio is significantly negatively correlated with the difference between companies in ROA (Table 15, M2: b = −3.035, SE = 0.442, $p = 0$). This implies that a 0.1 increase in the between-company difference in the current ratio is associated with a decrease of 0.3035% in the between-company difference in ROA. This result supports Hypothesis 1. This is because, during supply chain disruptions, many companies face financial constraints. Accumulating more cash at this time is not conducive to their development. It is worth noting that in Model 1, a within-company change in the current ratio significantly positively correlated with a within-company change in ROA. That is because before supply chain disruptions, in the short term, a healthy current ratio indicates lower liquidity risk, reducing the likelihood of financial distress. Lower financial risk can lead to better investor confidence and potentially higher valuation metrics, indirectly affecting ROA.

Hypothesis 2 stated that there would be a negative between-company relationship of fixed assets/total assets ratio and ROA during supply chain disruptions. The difference between companies in fixed assets/total assets ratio is significantly negatively correlated with the difference between companies in ROA (Table 15, M2: b = −30.33, SE = 6.719, $p = 0$). This implies that a 0.1 increase in the between-company difference in fixed assets/total assets ratio is associated with a decrease of 30.33% in the between-company difference in ROA during disruptions. Our findings provide validation for Hypothesis 2. This is because, during supply chain disruptions, the expansion strategy carries higher risks compared to pre-disruption conditions.

Hypothesis 3 stated that there would be a negative between-company relationship of growth and ROA during supply chain disruptions. The difference between companies in growth is significantly negatively correlated with the difference between companies in ROA in Model 2 (Table 15, M2: b = −0.143, SE = 0.017, $p = 0$). This implies that a 1% increase in the between-company difference in growth is associated with a decrease of 0.143% in the between-company difference in ROA. Our findings provide validation for Hypothesis 3. This is because, during supply chain disruptions, the expansion strategy carries higher risks compared to pre-disruption conditions.

Regarding the reason for disruptions, Gollakota and Shu (2023) observed an upward trend in renewable energy consumption patterns since 2019. The increasing demand for renewables has been driving up factory utilization rates within the industry. However, without the addition of extra capacity, this trend can heighten the susceptibility of supply chains to unforeseen disruptions (Bettoli et al. 2023). The regression results indicate that renewable energy firms should curtail expansion efforts during disruptions to optimize performance.

Although during supply chain disruptions, in general, reducing growth will contribute to ROA, it is not advisable for renewable energy companies to halt expansion efforts altogether. The escalating demand for renewables necessitates continued expansion. To enhance the resilience of the supply chain, it is crucial to foster transparency and communication, enabling various stakeholders to work together in addressing issues (Torres-Rivera et al. 2023). Effective communication with customers and original equipment manufacturers—using long-term partnership strategies—can help mitigate risks. For example, in the renewable energy industry, Ørsted, the Danish multinational power firm and the world's largest offshore wind developer, has used a long-term partnership strategy to stabilize the prices of important parts.

It is worth noting that in Model 1, a within-company change in growth significantly positively correlated with a within-company change in ROA. That is because before supply chain disruptions, in the short term, an increase in growth contributed to ROA.

Hypothesis 4 postulated a positive between-company relationship of R&D expense and ROA during supply chain disruptions. The difference between companies in R&D expense is significantly positively correlated with the difference between companies in ROA (Table 15, M2: b = 0.007, SE = 0.001, $p = 0$) (Table 15, M1: b = 0.013, SE = 0.007, $p = 0.044$). This implies that a $USD 1 million increase in the between-company difference in R&D expense is associated with a 0.007% increase in the between-company difference in ROA during supply chain disruptions and a 0.013% increase in the between-company difference in ROA before supply chain disruptions. Our findings provide validation for Hypothesis 4. That is because time is one of the most valuable assets. When there are no good chances to break through, doing what we can do well, such as research, will eventually provide us with an opportunity to break through. For example, implementing recycling programs and utilizing cutting-edge technologies can lessen dependence on essential materials such as lithium, and nickel, while also broadening the supply chain (Torres-Rivera et al. 2023).

For the control variable credit rating, we find a significant negative between-company relationship of credit rating and ROA, both before and during supply chain disruptions, indicating that lower creditrating (higher credit scores) is associated with higher ROA. For the control variable, the debt-to-assets ratio, we find a significant negative between-company relationship of debt-to-assets ratio and ROA during supply chain disruptions and a significant positive within-company relationship of debt-to-assets ratio and ROA, both before and during supply chain disruptions. That is because, in the short term, higher leverage enhances companies' capacity to invest in R&D. However, during supply chain disruptions, higher leverage increases the risk of default. For the control variable, average tax rate, we find a significant negative between-company relationship of average tax rate and ROA, both before and during supply chain disruptions, indicating that a higher average tax rate is associated with lower ROA.

For the control variable, total assets, we find a significant negative within-company relationship of total assets and ROA before supply chain disruptions. That is because, during 2017 and 2018, inventory increased substantially due to enhanced productivity. For the control variable, age, we find a significant negative between-company relationship of age and ROA after supply chain disruptions. That is because old renewable energy companies are more likely than new ones to encounter challenges related to outdated technology and fixed assets. These challenges are more obvious during supply chain disruptions. For the control variable, international business presence, we find a significant negative between-company relationship of international business presence and ROA after supply chain disruptions. That is because, during supply chain disruptions, there are more unseen risks in the international markets compared to the period before the disruptions.

6. Discussion and Conclusions

Before the disruptions, listed companies pursued different strategies compared to during disruptions. Overall, companies, especially those with positive ROA, tended to leverage additional funds for R&D investment and market expansion.

During the supply chain disruptions, our regression analysis suggests a shift in strategy for companies. It suggests that, in general, companies should reduce expansion efforts, especially in the absence of substantial government subsidies, prioritize cash allocation towards R&D, and avoid venturing into unfamiliar international markets. This strategic adjustment is supported by the correlation coefficients observed: there is a negative correlation between growth and ROA, while there is a positive correlation between R&D and ROA, consistent with the regression findings.

Some articles introduce examples of technical innovations that expand the supply chain. For instance, implementing recycling programs and utilizing cutting-edge technologies can lessen dependence on essential materials such as lithium and nickel, while also broadening the supply chain (Torres-Rivera et al. 2023). Our work empirically demonstrates the impact of R&D investment on ROA during supply chain disruptions. To significantly contribute to the literature and empirical practice concerning supply chain disruptions, future studies should explore various types of technical innovations influencing different facets of the supply chain.

Employing long-term partnership strategies can assist renewable energy companies in establishing robust relationships with suppliers of raw materials and equipment. In the event of supply chain disruptions, these suppliers ensure that their partnered renewable energy companies receive priority access to necessary resources and equipment. Additionally, they provide favorable pricing to these partnered companies.

Bioenergy companies, relying on organic materials often sourced locally or regionally, mitigate the impact of global supply chain disruptions. To keep pace with greenhouse gas reduction goals during supply chain disruptions, significant development of bioenergy companies is essential.

However, this paper's limitation lies in its exclusive focus on the strategies of large-scale listed companies, neglecting the innovative approaches of small-scale companies, which constitute a significant portion of the renewable energy sector. As previously mentioned, young companies may hold a technological edge and resilience during supply chain disruptions, underscoring the importance of exploring their strategies for policy formulation.

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