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Analysis of Decision Making of Energy Enterprises on Adaptive Behavior Amid COVID-19

*Xiurui Yang and Jizu Li**

College of Economics and Management, Taiyuan University of Technology, Taiyuan, China

There is no choice for energy businesses with ongoing epidemic prevention and control but to adapt themselves to the epidemic. Analyzing the decisions of energy enterprises on adaptive behaviors amid the Corona Virus disease 2019 (COVID-19) pandemic goes a long way toward economic and social stability and successful containment of the pandemic. With a phone-based or online (Tencent QQ and WeChat) survey on 500 energy companies in 17 prefecture-level cities and autonomous prefectures in Central China's Hubei Province, we examined the types of adaptive behavior these businesses had chosen to respond to the virus. We utilized the entropy weight method (EWM) and identified key factors that impacted how these companies made decisions on adaptive behavior. On that basis, we compared the samples with state-owned enterprises and private businesses in terms of the criticality of factors affecting their decisions on adaptive behavior. The significant findings are as follows. First, the adaptive behaviors of Hubei-based energy companies were for philanthropic, economic, or technical purposes. Besides, concerning the confidence level, the central government's general requirement for epidemic prevention and control, current economic realities, cost-benefit analysis of adaptive behavior, the awareness of corporate social responsibility, and energy policy support from governments were key factors that affect decisions of Hubei's energy enterprises on adaptive behavior. Their criticality rates 0.999 6, 0.999 5, 0.999 0, 0.997 1, and 0.995 8, respectively. Moreover, the key affecting factors of these samples differed from those of energy enterprises of a different nature. The nature of energy businesses holds sway over the identification of those key factors. The criticality of which also varies with the distinctive nature of the enterprises. Finally, we presented the theoretical implications of the present work and policy-making recommendations.

Keywords: COVID-19, epidemic, adaptive behavior, decision making, entropy weight method (EWM)

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China University of Mining and Technology, China

****Correspondence:***
Jizu Li
ljizu@tyut.edu.cn

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INTRODUCTION

As of November 17th, 2020, more than 55.3 million Corona Virus disease 2019 (COVID-19) cases were confirmed worldwide. Not only has the raging pandemic threatened the wellbeing of humankind, but it led to an uncertain global economic outlook. "Globally, the pandemic is actually speeding up," said Tedros Adhanom Ghebreyesus, Director-General of the World Health Organization. "The critical question that all countries will face in the coming months is how to live with this virus. That is the new normal." To reduce the impacts of the pandemic on the global economy, such international organizations as WTO, UNDP, IMF, and G20 have called on the

international community to take every necessary measure to curb the spread of the virus. It is widely accepted in the global community to adapt ourselves to new COVID-19 realities. How we live with the virus will be an inevitable part of all people's work and life for a long time to come, Dr. Barry R. Bloom, former Dean of Faculty at Harvard T.H. Chan School of Public Health stressed at the "Global Front Against COVID-19" symposium. Adaptation has been high on the global policy agendas on public health and economic recovery, and research efforts on adaptability brook no delay as the virus continues to spread, while pandemic prevention and control becomes part of the "new normal". Such studies were carried out by a great number of scholars across the world, and they focused on how local governments, along with urban and rural communities, took measures to adapt and respond to pandemics or public health emergencies of international concern, such as influenza (Nigmatulina and Larson, 2009; Kim et al., 2014; Reissman et al., 2011), malaria (Shretta et al., 2017; Obol et al., 2018), SARS (Leung and Won, 2005), Ebola (Abayomiet al. 2019; Carter et al., 2017), and COVID-19 (Angel and Mudrazija, 2020). Beyond that, some examined changes to trade policies given the spread of a pandemic and global economic recession (Pak et al., 2020; Brenton and Chemutai, 2020), while others studied how small and medium-sized businesses broke through, survived, and reenergized in a pandemic crisis (Zhang and Han, 2020). Most research based its analysis on the sustainable livelihoods framework, cognitive-behavioral theory, and the theory on the adaptability of social-ecological systems, and concentrated on exploring the stress response, social mentality, behavioral regulation, and coping strategy of organizations or individuals facing a pandemic (Gatiso et al., 2018; Main et al., 2011; Li et al., 2020b; Samaraweera, 2018). In a nutshell, the emphasis of previous studies was on how residents and such organizations as government agencies, urban and rural communities, and enterprises acted and took measures to adapt to a pandemic crisis and its aftermaths, and on the results that they achieved in this process. Nonetheless, little attention has been paid to the adaptability of energy enterprises to the COVID-19 pandemic, and the factors that affect decision making on their adaptive behaviors remain to be expounded.

Enterprises producing or marketing energy products are crucial for the availability of energy sources. These energy companies can ensure economic and social stability by supplying such strategic resources tied up with residents as electricity, natural gas, coal, and petroleum. As devoted formidable forces against COVID-19, they offered protective materials and daily necessities to hospitals, disease control centers, producers of medical supplies, high-speed rail stations, airports, and other facilities essential to people's wellbeing. Meantime, the supply and transportation of products of energy companies were hit hard by the epidemic, and the resumption of services, industry and commerce was slow and restricted, which resulted in a decrease in energy consumption. The epidemic posed a grave challenge to the survival and development of energy enterprises, and a heavy defeat was written in the stars as China's short-term energy consumption, as data showed, shrank by 15% (Li et al., 2020a). With ongoing epidemic prevention and control, there is no choice for energy businesses but to adapt themselves to the epidemic. The move concerns China's economic stability and security, as well as the quality of daily life among the general public.

Corporate nature is one of factors affecting decision making of energy businesses on adaptive behavior. Companies of a different nature result in the difference in the adoption of adaptive behaviors. Further analysis of the difference in the criticality of the impact that key affecting factors have on companies of varied nature is of practical significance and theoretical value to unveil the relationship between different types of energy enterprises and the factors affecting their decision making on adaptive behavior.

On that basis and with a survey of 500 energy enterprises based in 17 prefecture-level cities and autonomous prefecture in Hubei, the paper examined the types of adaptive behavior that these companies had chosen to respond to COVID-19 and by adopting the EWM, identified key factors that affect how these companies made decisions on adaptive behavior. Subsequently, the paper compared these samples with state-owned enterprises and with private businesses in terms of the criticality of factors affecting their decisions on adaptive behavior, with an aim to offer Chinese energy enterprises policy suggestions and a guideline on their sustainability under pressure from the epidemic.

OVERVIEW OF THE STUDY AREA AND DATA SOURCES

Overview of the Study Area

Hubei was the hardest-hit area by COVID-19, and its capital city Wuhan had been locked down starting from 10 a.m. on January 23, 2020. The 24 h closed-off management was put in place in villages, communities, and residential communities and areas across the province in a way never seen before. It was such a determined response that stopped the virus from spreading nationwide.

Epidemic prevention and control forced Hubei's energy enterprises to suspend their all or partial operations, and as a result, their revenue took a heavy toll. In 2020, among five Wuhan-registered companies listed in China A stock exchange, only Hubei Energy Group saw its first-quarter revenue flat with the level seen during the same period of the previous year due to an increase in power generation. The remaining four, namely SINOPEC Oilfield Equipment Corporation, Bestsun Energy, Kaidi Ecological and Environmental Technology, and Guodian Changyuan Electric Power, posted a year-on-year decrease in first-quarter revenue of 4.72, 23.24, 27.85, and 40.58%, respectively. That, compounded by sharp declines in business performance, threw them into a crisis of delisting from the stock market. While being active in responding to the changing epidemic by launching contingency plans, Hubei's energy companies worked to prevent and control the spread of the disease and maintained production and other operations. All these efforts provided a solid foundation in the province's ultimate victory over the fight against COVID-19 and in rapid economic recovery and social stability.

At the outset of the epidemic, Hubei-based energy enterprises owned by the Central Government promptly mobilized personnel and material resources to support the building of such large hospitals as Huoshenshan and Leishenshan, donated a large portion of funds to frontline virus control, and prepared emergency medical supplies, including protective suits, isolation gowns, goggles, and medical N95 masks. Some even leveraged their edges to turn to produce medical consumables, such as rubbing alcohol and raw materials for masks, in a way to meet the demand of the public for anti-epidemic supplies and contribute to Hubei's battle against the virus.

Data Sources

Sample data came from a large-scale questionnaire survey in Hubei that was carried out by a research group at Taiyuan University of Technology on "Advancing Energy Production and Consumption Revolution (2035)" between February and May 2020. Up to 500 energy companies in Hubei's 17 prefecture-level cities and autonomous prefecture were surveyed online (Tencent QQ and WeChat) or via phone. The focus of the questionnaire was four-fold. First, energy businesses' perception of the trends and impacts of epidemic developments. Wherein the former involved how they perceived the possibility of epidemic recurrences in the province, the coming of coronavirus variants, and the global trend of COVID-19 developments; the latter included their perception of the energy production and supply, consumer demand, and survival of industrial chains in Hubei, as well as of global economic recession and vaccine development progress. Second, adaptive behaviors of energy companies. The survey used open-ended and closed-end questions to document the adaptive behaviors of respondents, and in so doing, prepared a summary of how these companies acted to adapt to the epidemic. Third, factors that affect the decision making of energy companies on adaptive behavior. Respondents were asked to evaluate the criticality of affecting factors from the perspectives of economic benefits, social benefits, maneuver decision making, the efficiency and stability of decision making. Fourth, the nature of enterprises, by which companies can be either state-run or private and engage in operations of conventional or new energy sources.

The survey was conducted in two stages. In Stage One, which lasted from late February to early March, leaders of 230 energy enterprises were interviewed by phone and tape-recorded, and the answers respondents gave, upon the recording and replay debugging, made for the Survey on Adaptive Behaviors of Energy Enterprises amid COVID-19. The questionnaire is available at **Supplementary File 1**. Stage Two started in late april and ended in early May, during which 270 energy businesses were surveyed online. Among the 500 companies, state-owned enterprises and private businesses accounted for 67.3 and 32.7%. Moreover, conventional-energy and new-energy enterprises represented 71.6 and 28.4% of all respondents, respectively. The types of companies surveyed were consistent with those of all energy companies in Hubei, and that, therefore, met the stratified sampling requirement.

The study excluded the personal information of leaders of energy enterprises surveyed when they answered questions or filled out the questionnaire, which included the respondents' basic information, the extent to which they perceived epidemic developments, the actions taken during the epidemic, and how they evaluated the criticality of affecting factors. Having examined the validity of survey questions, we removed 14 questionnaires that were illogically answered or short of data, and the rest 486, or 97.2%, were considered valid. Besides, having used the SPSS 24.0 software to test the reliability and validity of these 486 questionnaires, we found the Cronbach's α coefficient of each factor ranged from 0.85 to 0.89, and the Kaiser-Meyer-Olkin (KMO) value was 0.879. That those values were greater than 0.7 suggested acceptable reliability and validity of the survey and satisfied the requirement of the study.

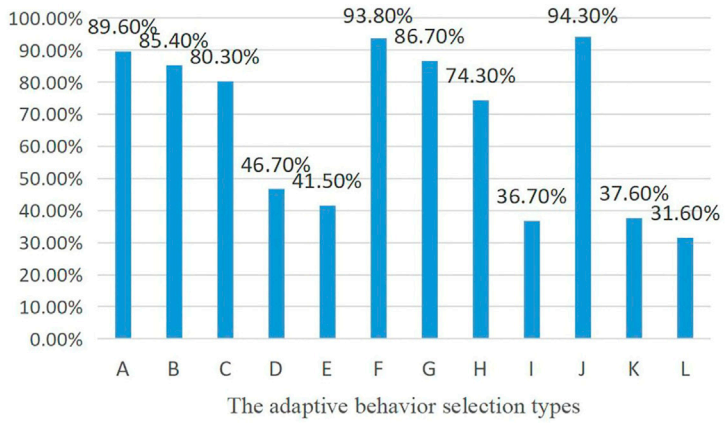
ADAPTIVE BEHAVIOR TYPES OF ENERGY ENTERPRISES

Generally, the business of energy enterprises was disrupted by the raging epidemic. That means adapting to the epidemic and working to put operations back on track were a sure way for these companies to sustain. According to descriptive statistics from the questionnaires, we identified the types of adaptive behaviors adopted by Hubei-based energy enterprises (**Figure 1**). The data are available at **Supplementary Data 1**.

Philanthropic Behavior

When things were at their most serious, energy companies in Hubei were courageous to shoulder corporate social responsibility and showed support for the hard-hit areas by carrying out charitable activities. To adapt themselves to epidemic prevention and control, some donated funds and materials, some ensured the supply of energy sources, and others helped build hospitals for emergency and even turned to produce medical raw materials. Companies giving funds, donating materials, and guaranteeing energy supply accounted for 87.6, 83.4, and 82.3% of all respondents, respectively. Donation of funds helped close the capital gap that authorities concerned confronted in sourcing protective materials. Purchasing medical masks, protective suits, and infrared thermometers before giving them to hospitals relieved the huge pressure from shortages of protective materials. The resumption of work, beyond the lowering of energy prices, ensured the massive support for virus control and economic recovery. Moreover, 46.7% of businesses surveyed mobilized a huge amount of people and materials to build such emergency hospitals as Leishenshan, Huoshenshan, and temporary treatment centers; 41.5% of respondents were dedicated to the production of medical raw materials in ways that ensured the supply of nonwoven fabrics, disinfectants, and medical oxygen. All these measures essentially strengthened companies' sense of social responsibility and made them all the more resilient in the face of the disease.

Overall, Hubei-based energy companies would take the initiative to respond to the abrupt epidemic challenges as a way to carry social responsibility. Compared to the private sector, state-owned companies, particularly those run by the Central Government, were more likely to adopt philanthropic behavior and engage in charitable endeavors.



A: Donation of Anti-Epidemic Funds	G: Suspension of Partial Operations
B: Donation of Anti-Epidemic Materials	H: Application for Tax Reductions and Exemptions
C: Assurance of Energy Supply	I: Production of Anti-Epidemic Materials
D: Support for Building Emergency Hospitals	J: Remote Work
E: Production of Medical Raw Materials	K: Equipment Going Digital
F: Human Cost Control	L: Automation in Manufacturing

FIGURE 1 | Adaptive behaviors adopted by energy companies.

Economic Behavior

It was a wise, realistic option for energy companies to make self-help efforts through a behavioral change economically, such as lowering the human cost, suspending partial operations, applying for tax cuts and exemptions, and turning to producing protective materials. Among all answerers, 93.8% opted to control their human cost, and 86.7% suspended part of their business. This way they could minimize losses so as to keep the essential business in normal, orderly operation. To lower the human cost, companies and their employees, through consultations, agreed on a pay adjustment and the schedule of rotating shifts. For unprofitable operations that require long-term investment, energy companies temporarily closed down some related plants or suspended the acceptance of orders, with an aim to respond to the epidemic while lightening the burden on capital. Moreover, China announced a host of tax reduction policies and exemption policies to compensate for those companies' economic losses from COVID-19. There are 74.3% of energy companies saw their financial difficulties eased by applying for the lawful postponement of tax payments and for low-interest loans. With an edge over raw materials, few energy businesses turned to producing much-needed medical products, all of which were purchased by governments for storage according to the system and measures for purchasing and storage during an epidemic. This lowered the costs of those producers and increased business income, ensuring their economic benefits.

Technical Behavior

Those opting for remote work, digitalizing their equipment, and automation in manufacturing accounted for 94.3, 37.6, and 31.6%, respectively, of the respondents. Among them, 94.3% would hold video conferences, coordinate management, and process business online through such online office software as DingTalk, Tencent Meeting, and WeChat Work. While allowing these companies to better connect to their staff, such behavior maximized the application of enterprise resources and considerably drove work efficiency. Meantime, boosting the pace of equipment to go digital by various technical means was a science-based decision that energy businesses made to adapt themselves to the coronavirus control. With that, 37.6% of them integrated their operations with such technologies as 5G and blockchain, upgraded online monitoring systems, and made contactless inspections on energy production and transportation through the video surveillance system. Given that some conventional energy companies came to realize the necessity of improving manufacturing processes, 31.6% of those surveyed rebuilt their assembly workshops by adding automated production lines. This was how they reduced dependence on labor while enjoying a surge in quality control, productivity and stability.

IDENTIFICATION OF KEY FACTORS AFFECTING DECISION MAKING ON THE ADAPTIVE BEHAVIOR OF ENERGY ENTERPRISES

Framework Building of Affecting Factors

Neoclassical economists believe that profit maximization is a necessary behavioral assumption that dictates how firms make output and pricing decisions. As always, enterprises would measure and examine the cost and benefit of adaptive behavior in a precise manner before developing a science-based evaluation system for comparison. On that basis, they

can make an informed decision on whether they should have a behavioral change or not and which aspects they should adopt new behavior (Ahmad, 2001; Moller, 2006). Within ownership determinism theory, enterprise behavior is subject to the structure of the ownership system, which also has an extensive impact on decision making of enterprise behavior, and for firms of a different nature, their behavioral pattern and orientation vary (Yu and Jiang, 2004). The more resources a company has, including labor, natural endowment, materials, financial strengths, and social capital, the more likely it is to adopt adaptive behavior (Rastogi, 2000; Ko et al., 2018). As a key indicator of core competitiveness, innovative capacity would make a company significantly resilient (Smit, 2015; Li et al., 2019), whereas leadership holds key to whether a decision on some adaptive behavior is appropriate or not (Ready and Peebles, 2015). Meantime, firms must be keenly aware that commitment to social responsibility enhances the legitimacy of their establishment in society and the adaptability of behavioral decision making, and ultimately gains respect and recognition from the general public (Wu et al., 2021; Málovics et al., 2006). During COVID-19, the perception of epidemic developments represents the barometer of how firms should make behavioral decisions to meet market changes (Jin, 2020). Current economic realities present businesses with an opportunity and also a challenge. Not only does the new landscape make an extensive and far-reaching impact on the way firms produce and operate, but changes the previous pattern of how they make decisions on adaptive behavior (Jbilou et al., 2007). For energy companies, favorable energy policies are a matter of critical concern because the prospect of the energy sector is linked to the planning for enterprise development and the industrial layout, both of which pave the way for decision making on the adaptive behavior of these firms (Nicolli and Vona, 2012; Rosenkranz et al., 2017) Given that uncertain coronavirus developments disrupted global energy demand, energy businesses faced increased stress in production and operation and were forced to make a choice about which adaptive behavior they should adopt (Fu and Shen, 2020; Ghiani et al., 2020). Against the backdrop, the CPC Central Committee put forth a general requirement on nationwide epidemic prevention and control, which involves ordering enterprises to adapt themselves to the health crisis (Hu, 2020). Governments at all levels provided policy support for businesses to better adapt to a new reality (Huang, 2020).

Building on neoclassical economics, ownership determinism theory, and corporate capital theory, scholars have explored the factors that affect the decision making on the adaptive behavior of enterprises by means of quantitative analysis, case study, and empirical research. Factors that have been identified include the cost-benefit comparison of adaptive behaviors, the nature, capital, innovative capacity, leadership, social responsibility, and epidemic developments perception of enterprises, the current economic landscape, energy policy orientation, the outlook of the energy industry, uncertainties presented by COVID-19, China's general requirement on virus control, and support from governments. The 13 factors above constituted the framework of factors that have an impact on how energy firms make decisions on a behavioral change.

Calculation of Entropy Weight in Evaluation Criteria

Setting of Variables

The set of factors affecting decision making of Hubei-based energy companies on adaptive behavior $Y = \{y_1, y_2, \cdots, y_{13}\}$ was established, wherein y_1 is the cost-benefit comparison of adaptive behaviors; y_2 corporate nature; y_3 corporate capital; y_4 innovative capacity; y_5 social responsibility; y_6 epidemic developments perception; y_7 competencies of leaders; y_8 the current economic landscape; y_9 energy policy orientation; y_{10} the outlook of the energy industry; y_{11} uncertainties presented by COVID-19; y_{12} China's general requirement on virus control; and y_{13} government support.

Selection of Evaluation Criteria

The factor set $X = \{x_1, x_2, x_3, x_4, x_5\}$ was selected as the evaluation criteria system for measuring the criticality of affecting factors, wherein x_1 represents the impact of economic benefits; x_2 the impact of social benefits; x_3 the impact of maneuver decision making; x_4 the impact of decision making efficiency; and x_5 the impact of decision making stability.

Setting of the Reviews Set

A typical five-level Likert item was employed to scale responses and set up the reviews set $V = \{v_1, v_2, v_3, v_4, v_5\} = \{$Severe Impact, Major Impact, Moderate Impact, Minor Impact, Insignificant Impact$\}$, and its corresponding assignments set $\overline{V} = \{5, 4, 3, 2, 1\}$. To render measurement results more accurate and science-based and minimize the error brought by subjective reviews, an evaluation index system was introduced to narrow the difference between adjacent grades and set up respective assignment standards in correspondence with values in descending order from 4.5 to 3.5 to 2.5 and to 1.5.

Establishment of the Fuzzy Evaluation Matrix

To avoid distractions of uncertain elements in decision making and make measurement results and quantitative interpretation more reliable and science-based, for an evaluation matter that contains m evaluation criteria $x_i\,(i = 1, 2, \ldots, m)$, and n evaluation objects/impact factors $y_j\,(j = 1, 2, \cdots, n)$, the decision of an expert group represents a common approach to obtain the fuzzy evaluation matrix A:

$$A = \begin{array}{c} \\ x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} y_1 & y_2 & \cdots & y_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ a_{31} & a_{32} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \end{array}$$

wherein the assignment value of element a_{ij} indicates the composite grade given to the evaluation object j according to evaluation criterion i.

In this study, the final assignment value of element a_{ij} came from the average of all sample data. According to five evaluation criteria $x_i\,(i = 1, 2, 3, 4, 5)$, experts graded each of 13 evaluation objects/impact factors $y_j\,(j = 1, 2, \ldots, 13)$ before acquiring the fuzzy evaluation matrix A:

$$A = \begin{bmatrix} 5 & 3 & 4 & 2.5 & 3 & 3 & 3 & 5 & 4 & 3.5 & 3 & 4 & 4 \\ 4 & 3 & 2 & 2 & 5 & 3.5 & 3.5 & 3.5 & 4 & 3 & 3.5 & 4.5 & 3 \\ 4 & 3 & 3.5 & 3 & 4 & 3.5 & 2.5 & 4 & 3 & 2.5 & 3.5 & 4.5 & 3 \\ 4 & 3.5 & 3 & 3.5 & 4 & 3 & 3.5 & 4 & 4 & 2.5 & 3 & 4 & 3.5 \\ 3.5 & 3 & 3.5 & 3 & 3.5 & 2.5 & 3.5 & 4.5 & 3.5 & 3 & 3 & 4.5 & 3 \end{bmatrix}$$

Standardization (Nondimensionalization) of the Fuzzy Evaluation Matrix

The standardized treatment can eliminate the deviations among various characteristic variables to ensure the reliability of data. Hence, upon the treatment of raw data in the fuzzy evaluation matrix A, we obtained the standardized matrix R:

$$R = \left(r_{ij}\right)_{5\times 13}$$

wherein $r_{ij} = \frac{a_{ij} - \min\limits_{j}\{a_{ij}\}}{\max\limits_{j}\{a_{ij}\} - \min\limits_{j}\{a_{ij}\}}$ and $r_{ij} \in [0, 1]$. That indicates.

$$R = \begin{bmatrix} 1.0000 & 0.2000 & 0.6000 & 0.0000 & 0.2000 & 0.2000 & 0.2000 & 1.0000 & 0.6000 & 0.4000 & 0.2000 & 0.6000 & 0.6000 \\ 0.6667 & 0.3333 & 0.0000 & 0.0000 & 1.0000 & 0.5000 & 0.5000 & 0.5000 & 0.6667 & 0.3333 & 0.5000 & 0.8333 & 0.3333 \\ 0.7500 & 0.2500 & 0.5000 & 0.2500 & 0.7500 & 0.5000 & 0.0000 & 0.7500 & 0.2500 & 0.0000 & 0.5000 & 1.0000 & 0.2500 \\ 1.0000 & 0.6667 & 0.3333 & 0.6667 & 1.0000 & 0.3333 & 0.6667 & 1.0000 & 1.0000 & 0.0000 & 0.3333 & 1.0000 & 0.6667 \\ 0.5000 & 0.2500 & 0.5000 & 0.2500 & 0.5000 & 0.0000 & 0.5000 & 1.0000 & 0.5000 & 0.2500 & 0.2500 & 1.0000 & 0.2500 \end{bmatrix}$$

Calculation of the Fuzzy Entropy Value

The entropy value suggests the dispersion of an indicator. For a fuzzy evaluation matter that contains m evaluation criteria and n evaluation objects, we employed the equation:

$$H_i = -k\sum_{j=1}^{n}\left[r_{ij}\ln r_{ij} + \left(1 - r_{ij}\right)\ln\left(1 - r_{ij}\right)\right] \quad i = 1, 2, \ldots, m. \quad (1)$$

to calculate the fuzzy entropy (Han and Wang, 1998) according to evaluation criterion i. $k = 1/n\ln 2$ indicates a constant term, and where $r_{ij} = 0$, $r_{ij}\ln r_{ij} = 0$ is allowed and the fuzzy entropy value H_i satisfies $H_i \in [0, 1]$.

In our case, where $m = 5, n = 13$, the fuzzy entropy value in evaluation criteria was calculated using **Eq. 1**, with results shown below:

$$H_1 = 0.6511;\ H_2 = 0.7109;\ H_3 = 0.6676;\ H_4 = 0.4945;$$
$$H_5 = 0.6966$$

Calculation of Entropy Weight

For the calculation of the entropy weight in evaluation criterion j, the equation is as follows.

$$w_i = \frac{1 - H_i}{\sum\limits_{i=1}^{m}(1 - H_i)} = \frac{1 - H_i}{m - \sum\limits_{i=1}^{m} H_i}. \quad (2)$$

On the basis of **Eq. 2**, we calculated the assignment value of entropy weight according to the set evaluation criteria, which are shown below.

$$w_1 = 0.1961;\ w_2 = 0.1625;\ w_3 = 0.1868;\ w_4 = 0.2841;$$
$$w_5 = 0.1705$$

Analysis of Affecting Factors in the Entropy Weight-Based Decision-Making Model

Solution to the Normalized Weighted Matrix B

The weighted operation of the assignment value of entropy weight on standardized matrix R led to the normalized weighted matrix B:

$$B = \begin{bmatrix} w_1 r_{11} \cdots w_1 r_{1n} \\ \vdots \ddots \vdots \\ w_m r_{m1} \cdots w_m r_{mn} \end{bmatrix} = \begin{bmatrix} b_{11} \cdots b_{1n} \\ \vdots \ddots \vdots \\ b_{m1} \cdots b_{mn} \end{bmatrix}$$

$$= \begin{bmatrix} 0.1961 & 0.0392 & 0.1177 & 0.0000 & 0.0392 & 0.0392 & 0.0392 & 0.1961 & 0.1177 & 0.0784 & 0.0392 & 0.1177 & 0.1177 \\ 0.1083 & 0.0542 & 0.0000 & 0.0000 & 0.1625 & 0.0812 & 0.0812 & 0.0812 & 0.1083 & 0.0542 & 0.0812 & 0.1354 & 0.0542 \\ 0.1401 & 0.0467 & 0.0934 & 0.0467 & 0.1401 & 0.0934 & 0.0000 & 0.1401 & 0.0467 & 0.0000 & 0.0934 & 0.1868 & 0.0467 \\ 0.2841 & 0.1894 & 0.0947 & 0.1894 & 0.2841 & 0.0947 & 0.1894 & 0.2841 & 0.2841 & 0.0000 & 0.0947 & 0.2841 & 0.1894 \\ 0.0852 & 0.0426 & 0.0852 & 0.0426 & 0.0852 & 0.0000 & 0.0852 & 0.1705 & 0.0852 & 0.0426 & 0.0426 & 0.1705 & 0.0426 \end{bmatrix}$$

Establishment of Ideal Points and Negative Ideal Points

The ideal point and negative ideal point of the normalized weighted matrix B are expressed by P^* and $P*$, respectively, which can be solved using the double-base method:

$$P^* = \left(p^*_1, p^*_2, \ldots, p^*_m\right)^T, P* = \left(p*_1, p*_2, \ldots, p*_m\right)^T,$$

where p^*_i and $p*_i$, the element of P^* and $P*$, satisfy the following conditions, respectively:

$$p^*_i = \max_j\left\{b_{ij}\middle|j = 1, 2, \ldots, n;\ i = 1, 2, \ldots, m\right\},$$
$$p*_i = \max_j\left\{b_{ij}\middle|j = 1, 2, \ldots, n;\ i = 1, 2, \ldots, m\right\}.$$

Hence, the ideal point P^* and negative ideal point $P*$ were established:

$$P^* = (0.1961,\ 0.1625,\ 0.1868,\ 0.2841,\ 0.1705)^T,$$
$$P* = (0, 0, \cdots, 0)^T.$$

Calculation of Fuzzy Nearness

The column vector $B_j = (b_{1j}, b_{2j}, \ldots, b_{mj})^T \quad j = 1, 2, \ldots, n,$ was separated from the normalized weighted matrix B and leverage the below equation:

$$t_j = \frac{\left(P^* - B_j\right)^T\left(P^* - P*\right)}{\left\|P^* - P*\right\|^2} = \frac{\left(P^* - B_j\right)^T P^*}{\left\|P^*\right\|^2} = 1 - \frac{B_j^T P^*}{\left\|P^*\right\|^2} \quad (3)$$

to calculate the relative nearness between each evaluation object/affecting factor $x_i\,(i = 1, 2, \ldots, 12)$ and the aforementioned ideal point P^* (Guo and Jia, 1990). The value range of t_j clearly satisfies $0 \le t_j \le 1,\ j = 1, 2, \ldots, n,$. In sequencing evaluation plans, much literature considered the value of t_j as a criterion, and the smaller the value, the better (Chen and Qiu, 2003). Moreover, Liu Shulin, a Chinese scholar, simplified the way the nearness is calculated (Liu and Qiu, 1998):

$$d_j = Bj^T P^*,\ j = 1, 2, \ldots, n, \quad (4)$$

where d_j obviously satisfies $0 \le d_j \le \left\|P^*\right\|^2$. That means when using the d_j value as a criterion to sequence evaluation plans, the optimal value should be the greater one. By employing the method Liu proposed, which is **Eq. 4**, we measured each d_j value, with results shown below:

$$d_1 = 0.1775;\ d_2 = 0.0863\ ;\ d_3 = 0.0820$$
$$d_4 = 0.0698;\ d_5 = 0.1555\ ;\ d_6 = 0.0652$$
$$d_7 = 0.0892;\ d_8 = 0.1876;\ d_9 = 0.1447$$
$$d_{10} = 0.0314;\ d_{11} = 0.0725;\ d_{12} = 0.1898$$
$$d_{13} = 0.1017$$

Setting of the Membership Function.

As a key indicator and method for measuring the extent to which two fuzzy sets are similar to or near each other, nearness represents a fuzzy value that, more often than not, is used to optimize the index weight in the overall evaluation. According to the description of the significance and character of the double-base method, the criticality of evaluation object/affecting factor y_j can be defined by nearness $d_j\,(d_j \geq 0)$. Hence, we introduced the Cauchy membership function $\mu(x)$ (Zhang et al., 1992):

$$\mu(x) = \begin{cases} 1 & x > a, \\ \dfrac{1}{1 + (x-a)}, & x \leq a. \end{cases} \tag{5}$$

.

Equation 5 was then used to describe criticality y_j, where in $a = \|P^*\|^2 = 0.2029$.

Calculation of Key Impact

We assigned nearness d_j to variable x in the aforementioned membership function $\mu(x)$ and upon calculation, solved the respective criticality $\mu(d_j)$ of each affecting factor y_j:

$$\mu(d_1) = 0.9990;\ \mu(d_2) = 0.9850;\ \mu(d_3) = 0.9840$$
$$\mu(d_{10}) = 0.9693;\ \mu(d_{11}) = 0.9816;\ \mu(d_{12}) = 0.9996$$
$$\mu(d_{13}) = 0.9885$$

Upon the sequencing of criticality $\mu(d_j)$ came the order of corresponding affecting factors, which is displayed below:

$$y_{12} > y_8 > y_1 > y_5 > y_9 > y_{13} > y_7 > y_2 > y_3 > y_{11} > y_4 > y_6 > y_{10}$$

Obtainment of the Key Affecting Factor Set Y_λ

For the key affecting factor set Y_λ, the Chinese scholar Chen Liming (Chen and Qiu, 2003) gave the following definition:

$$Y_\lambda = \left\{ y_j \middle| \mu\left(d_j\right) \geq \lambda,\ j = 1, 2, \cdots, n \right\}$$

In Y_λ, λ is expressed as the critical threshold or confidence level, and satisfies $\lambda \in [0, 1]$.

In this paper, the assignment value of λ was 0.99, which led to the following key affecting factor set $Y_{0.99}$:

$$Y_{0.99} = \{y_{12}, y_8, y_1, y_5, y_9\}$$

That suggests on the condition that $\lambda = 0.99$, the key factors that affect the decision making of Hubei-based energy companies on adaptive behavior were y_{12} (China's general requirement on virus control), y_8 (the current economic landscape), y_1 (the cost-benefit comparison of adaptive behaviors), y_5 (corporate social responsibility), and y_9 (energy policy orientation).

COMPARATIVE ANALYSIS OF KEY AFFECTING FACTORS

As one of the factors affecting decision-making of energy businesses on adaptive behavior, corporate nature hinges upon their position in the social economy. Companies of a different nature have a varied preference for the business environment and policies, which results in the difference in adopting adaptive behaviors, and the perception of and attitude toward key affecting factors.

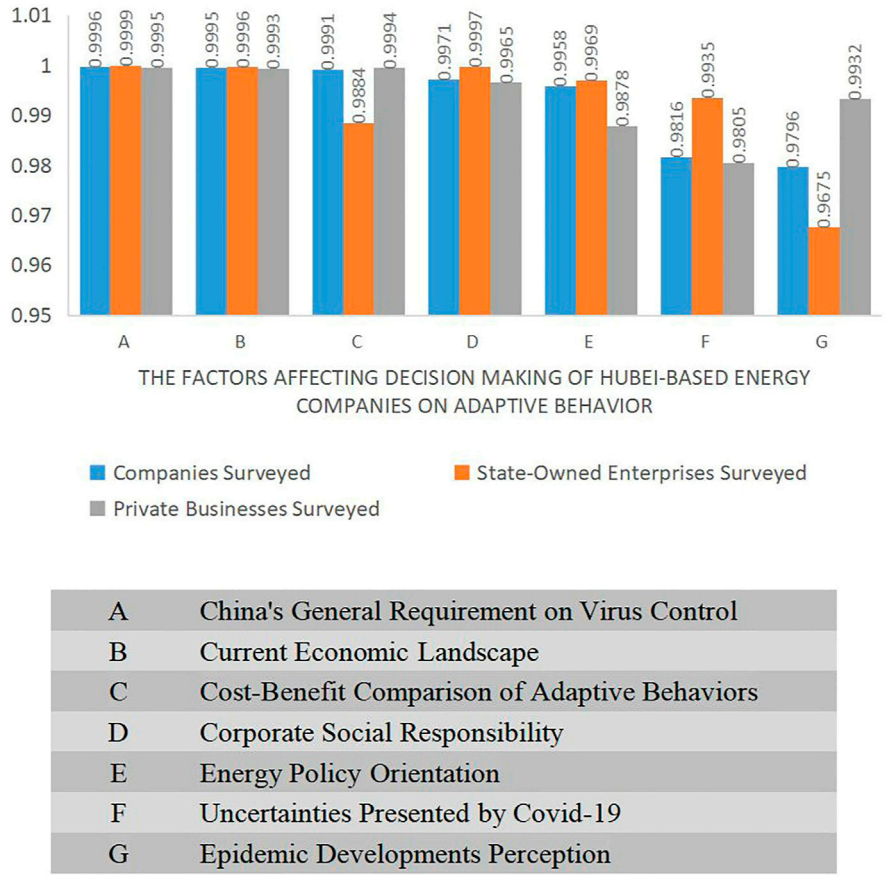
In light of the nature of respondents, the sample data was divided into data provided by state-owned companies and those by private businesses. The data are available at **Supplementary Data 2**. Upon analyzing the entropy weight-based decision-making model, the results suggested that when the confidence level $\lambda = 0.99$, the sets of key affecting factors were $Y_\lambda = \{y_{12}, y_5, y_8, y_9, y_{11}\}$ and $Y_\lambda = \{y_{12}, y_1, y_8, y_6, y_5\}$, respectively, both different from that of all samples. The comparison diagram on the criticality of key factors affecting decision making on the adaptive behaviors of all respondents, state-run companies, and private businesses is shown in **Figure 2**.

The distribution of criticality of key affecting factors in **Figure 2** has two main features.

1) For all surveyed, including those of a different nature, China's general requirement on virus control, current economic landscape, and corporate social responsibility are shared key affecting factors. Whatever type of companies is, China's general requirement on virus control is regarded as the most critical factor that affects decision making of energy companies on adaptive behavior as it overtakes other affecting factors in criticality. For all respondents and private firms, the criticality of current economic realities is greater than that of corporate social responsibility, while the case with state-run companies is on the contrary.
2) The criticality of the cost-benefit comparison of adaptive behaviors ranks second among other key factors that have an impact on decision making of private companies on adaptive behavior, but still cannot constitute the key factor set of state-owned enterprises. On the contrary, energy policy orientation is not part of the private sector's key factor set despite its fourth place in terms of the criticality of its impact on the behavioral decision-making of state-owned companies. Uncertainties presented by COVID-19 for state-run enterprises and epidemic developments perception by private firms are two critical factors excluded from the key factor set of all samples.

POLICY-MAKING RECOMMENDATIONS

1) To encourage energy enterprises to make a behavioral change, local governments should work to understand and implement the general requirement on nationwide corona virus control put forth by the CPC Central Committee and the State Council. That means they need to stay committed to epidemic prevention and control by shoring up the weak spots thereof and improving and carrying out anti-epidemic measures.
2) Governments should pick up the pace of the development of economic recovery plans and issue a large-scale package of



A	China's General Requirement on Virus Control
B	Current Economic Landscape
C	Cost-Benefit Comparison of Adaptive Behaviors
D	Corporate Social Responsibility
E	Energy Policy Orientation
F	Uncertainties Presented by Covid-19
G	Epidemic Developments Perception

FIGURE 2 | The comparison diagram on the criticality of key factors affecting decision making on the adaptive behaviors of all respondents, state-owned companies, and private businesses.

economic stimulus. In so doing, they need to restart the economy in a quick manner by stimulating domestic consumption through a host of measures, such as the issuance of shopping coupons. Moreover, greater efforts should be made to optimize the structure of energy sources, step up investment in renewable energy, and accelerate the pace of energy infrastructure building. This is how governments improve the quality of China's economic and social development.

3) Governments should provide energy companies that were hit hard by COVID-19 with necessary financial support or assistance, such as concessionary financing, tax reduction and exemption, postponement of bank loans, and granting of allowances. Such measures allow businesses to lower the cost of having behavioral change while increasing earnings thereof.
4) Government functions need to be transformed. Specifically, governments should improve the legal system for responding to emergencies of major concern, rebuild the model for administering the society, and step up publicity and supervision. Beyond that, Chinese energy companies should be motivated to participate in the timely response and handling of public health emergencies as a way to strengthen their sense of social responsibility.
5) While concentrating on current coronavirus control realities and global economic developments, governments should continue to give priority to energy security and be oriented to green development in formulating policies. And more efforts need to be made to carve out a novel development model and optimize the structure of energy supply. On top of reducing the excess capacity of coal and coal power, governments should build a diverse energy supply system by launching various programs on renewable energy sources, including solar energy, wind power, biomass energy, and geothermal power. When it comes to policy development, the difference in regions, industries, and technological and economic conditions should be taken into account, so as to render policy resilient and effective.
6) On state-owned energy enterprises, governments should adopt proactive fiscal policy and moderately loosened monetary policy to give certainties to and share risks with companies as they pursue sustainable development. On top of that, holistic efforts should be made to drive economic growth and consolidate virus control by businesses. This way uncertainties brought by COVID-19 can be coped with by targeted policies, and businesses will thus be more confident about the economic rebound plan. As to private energy firms, governments need to put in place online platforms for government-enterprize interaction, on which businesses can be kept informed about updates on COVID-19 so as to help them better perceive epidemic developments.

CONCLUSION

With a phone-based or online (Tencent QQ and WeChat) survey of 500 energy enterprises based in 17 prefecture-level cities and autonomous prefecture in Hubei Province, the paper examined the types of adaptive behavior these companies had chosen to respond to COVID-19 and by using the EWM, identified key factors that have an impact on how these businesses made decisions on adaptive behavior. Building on that, it compared the samples with state-owned enterprises and with private businesses in terms of the criticality of factors affecting their decisions on adaptive behavior. The major findings are as follows.

1) The types of adaptive behavior that Hubei-based energy companies chose consisted of philanthropic behavior (including the donation of anti-epidemic funds and materials, guarantee of energy supply, support for the building of emergency hospitals, and production of medical raw materials), economic behavior (including human cost control, suspension of partial business, application for tax reductions and exemptions, and production of protective materials), and technical behavior (including remote work, equipment going digital, and automation in manufacturing).
2) On the condition that, the critical factors that affect the decision making of Hubei's energy enterprises on adaptive behavior were China's general requirement on virus control, the current economic landscape, the cost-benefit comparison of adaptive behaviors, corporate social responsibility, and energy policy orientation, with the first two taking the lead among others. Moreover, profit maximization is what companies are eager to achieve in business production and operation, and an essential criterion for profitability is the cost-benefit comparison of businesses' adaptive behavior, which also drives their decision making on such behavior. Meantime, energy businesses followed government orders to contain the virus by quickly resuming production and ensuring the supply of protective materials as a way to show their social responsibility. Fundamentally, all these drove their decision making on adaptive behavior. Energy policy orientation, however, has a primary, guiding, or even decisive role to play. It can either drive the growth of energy businesses forward or slow it down, while exerting a direct, significant impact on decision making on their adaptive behavior.
3) When, the key factors affecting the decision making of all respondents and companies of a different nature on adaptive behavior varied. Indeed, the nature of energy companies held sway over their understanding of critical affecting factors, whose criticality would change accordingly.

Analyzing the decisions of energy enterprises on adaptive behaviors amid the COVID-19 pandemic goes a long way toward economic and social stability and successful containment of the pandemic. Thus, this study probed into the decision-making of energy enterprises on adaptive behaviors amid the pressure of the COVID-19 pandemic and achieved conclusions of both theoretical and practical significance. However, as the impacts of the COVID-19 pandemic are manifold, the adaptive-behavior decisions of energy enterprises are diverse, and the authors have limited expertize in this regard, the research shows some limitations, and some questions remain to be further explored. ①The contributing factors to the decision-making of energy enterprises on adaptive behaviors are manifold. The framework of contributing factors established in the present work is not complete. Many factors concerning the spread of the COVID-19 virus have not been incorporated into the framework, limiting the universality of the research on the identification of the key contributing factors. ②Though the criticality of contributing factors has been identified, the influencing mechanism of the key contributing factors to the adaptive behavior decision-making of energy enterprises has not been revealed, and the specific impact of the COVID-19 pandemic on the enterprises' decision-making has not been analyzed in detail. Future studies will probe into the influencing mechanism of the COVID-19 pandemic on the decision-making of energy enterprises on their adaptive behaviors and the impact of the spreading characteristics of the COVID-19 virus on differentiated choices of enterprises.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

XY: methodology; investigation; data curation; writing—original draft preparation; writing—review and editing. JL: project administration; funding acquisition. All authors approved the final version to be published.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenrg.2021.716171/full#supplementary-material

Supplementary File 1 | The survey on adaptive behaviors of energy enterprises amid COVID-19.

Supplementary Data 1 | The types of adaptive behaviors adopted by Hubei-based energy enterprises.

Supplementary Data 2 | The evaluation assignment value (mean value) of the criticality of affecting factors by energy enterprises.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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