Applied Energy 375 (2024) 124069

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Manufacturers' power strategy confronting marine energy instability and consumers' environmental concern: Incentive and data-driven policy analysis

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HIGHLIGHTS

- Two power strategies are formulated for energy supply chain operations
- A two-pronged approach to technology development and green education can better drive manufacturers to use marine energy.
- Economic and environmental performances under four strategy combinations are evaluated
- Consumers' green concern may lead to a worse environmental performance under certain conditions

ARTICLE INFO

Keywords:
Energy system modeling
Sustainable operations
Marine energy
Energy supply chain
Power stability
Game theory

ABSTRACT

Marine energy, as a renewable and environment-friendly energy, has presented promising solutions amid consumers' green concerns. However, manufacturers have to take the risk of marine energy's supply instability and green competition with market competitors. This study therefore investigates two competing manufacturers' equilibrium power strategies when they decide whether to use marine energy. We define the manufacturer's use of electricity from a fossil fuel power supplier as strategy T, and from a marine energy power supplier as strategy M. Our findings indicate that four strategy combinations may sustain as the equilibriums: (T,T), (M,T), (T,M) and (M,M), depending on the sophisticated interactions of consumers' environmental concerns, marine energy stability and competition intensity. We identify *the marine energy advantage* and *the demand shrinking effect* to interpret the main findings. *The marine energy advantage* refers to the increased demand from eco-friendly consumers when using marine energy. *The demand shrinking effect* refers to the narrowing of demand due to increasing product homogeneity. We further find that the different competition landscapes drive power suppliers to adjust their power prices and thus affect the equilibriums, which is defined as *the power price effect*. Interestingly, we show that consumers' green concern may lead to a worse environmental performance because green demand is created but marine energy supply instability will induce the manufacturer with a larger demand size to opt for polluting and stable fossil energy power.

1. Introduction

In recent years, the exploration of alternative energy sources has become imperative in the face of growing environmental concerns and the need for sustainable energy solutions. The potential of marine energy is undeniable, as highlighted by the Intergovernmental Panel on Climate Change (IPCC) report, which shows the potential of marine energy can reach 7400 EJ/year, far exceeding humanity's current and future energy needs [1]. Similarly, the International Renewable Energy Agency notes that marine energy could meet more than twice the current global electricity demand [2]. Keeping these forecasts in mind, many countries, especially those with limited land-based resources, have actively declared their commitment to the vigorous development of marine energy.

A notable example is the UK, which indicates considerable marine energy resources of high quality need to be exploited to make marine energy an important part of the government's energy mix [3-5]. Denmark's government has similarly launched an agreement to double its

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https://doi.org/10.1016/j.apenergy.2024.124069
Received 2 May 2024; Received in revised form 15 June 2024; Accepted 25 July 2024

commitment to Energy Island and dedicate more of its sea area to marine energy development [6]. Meanwhile, we observe that more and more giant companies are willing to use sustainable energy sources in their production processes [7,8]. For example, Apple, Microsoft, and Google have made significant strides in this regard by joining the RE100 initiative, which requires the participating companies to commit to using exclusively green power by 2050 [9,10]. Some pioneer companies have already transitioned to 100% renewable energy in manufacturing. For instance, White Wave's Silk and Horizon brands are produced entirely using renewable energy sources (Science [11]), which can be labeled with eco-friendly symbols on the packages such as the famous "Green-e®" logo to attract consumers with environmental concerns [7]. Similarly, Tsingtao Brewery, a Chinese beer company, uses 100% renewable energy in the production of its 31 factories [12].

However, when it comes to marine energy, the use becomes a double-edged sword: Marine energy relies on the natural environment so the supply is subject to significant uncertainty, making it challenging to accurately predict the long-term energy output [1,13,14]. Consequently, manufacturers who aim to exclusively utilize marine energy in their production processes may encounter difficulties due to the instability of the energy supply. This instability can lead to significant yield problems, where the successful product output in due time will be a proportion of the order quantity [8]. We note that most of the existing research has focused on manufacturers' power strategy without the consideration of downstream market competition and the interaction with the upstream energy suppliers' decisions. The investigation of unstable energy supply also appears new because previous literature has mainly revealed the environmental value of renewable energy (e.g., marine energy) but ignored the dark side of using such energy, i.e., the supply instability issue.

The above discussions and observations lay the fundamental motivation for our study. We aim to show the manufacturers' strategic decisions in using fossil fuels or marine energy, especially when downstream competition is taken into account. we raise the following questions:

- What's the power strategy in equilibrium? What are the underlying driving forces?
- Will the manufacturers' power strategy really improve environmental sustainability?

We develop a three-stage optimization model with four strategy combinations to answer the forgoing questions. There are two competing manufacturers who have the option to choose different power suppliers, they can either use fossil power or marine energy for production. Opting for marine energy, the manufacturer can sufficiently attract green-minded consumers so demand creation by eco-friendly consumers is expected, but it comes along with production yield uncertainty problems due to the supply instability associated with marine energy. Note that, the higher the technology level of marine energy, the lower the supply instability and hence, the slighter the production yield problem.

Our findings reveal that the use of marine energy is positively influenced by the attractiveness of green-minded consumers. We refer to this as *the marine energy advantage*, which will be amplified if the yield problem is not significant. As the product homogeneity increases, the demand size becomes narrower, leading to smaller manufacturers' order quantities. We refer to this as *the demand shrinking effect.* Further, the power supplier(s) will adjust power prices to influence intensified competition in downstream markets, which we refer to as *the power price effect.* When the two manufacturers' products are very heterogeneous/homogeneous, they will be more likely to use fossil/marine energy, depending on the interaction of the three effects mentioned above. Otherwise, when their products' differentiation is of a moderate degree, the two manufacturers will be more inclined to choose different power suppliers, resulting in asymmetric strategy equilibrium. By this two manufacturers will compete differentiatedly because one benefits from *the marine energy advantage* while the other benefits from lower power price due to *the power price effect.* Surprisingly, we find that with a substantial *marine energy advantage*, the manufacturer with weak brand competitiveness will use marine energy, while the more brand-competitive manufacturer with a larger demand size and incurring more carbon emissions will choose the polluting fossil power. Compared with the literature, we reveal an interesting finding that using marine energy may have an adverse effect on environment. We extend Niu et al. [8] and Rajabzadeh and Wiens [15] by exploring the power strategy choice game between competing manufacturers. We also show how the energy suppliers' dynamic pricing behavior interacts with unstable energy supply and consumers' environmental concerns.

Next, we will review the relevant literature in section 2. Section 3 introduces the model setting. We analyze the equilibrium outcomes in Section 4 and further study the environmental performance in Section 5. A numerical study based on real-world data is adopted to elucidate our results in Section 6. Section 7 examines (1) consumer preferences for different strategy combinations; (2) the impact of fossil fuel cost; and (3) the impact of carbon emission from marine energy power. Section 8 concludes this paper and discusses several future research directions. For the sake of brevity, we put all the proofs in the Appendix.

2. Literature review

This study is closely related to the literature on energy supply chain. Considering the uncertainty of demand and fuel costs, Wang et al. [16] examine firms' capacity decisions under the trade-offs between traditional and sustainable technologies. Yang et al. [17] optimize the time-of-use pricing strategies in an energy supply chain. Dong et al. [18] analyze optimal capacity investment and pricing decisions for electricity companies under stochastic demand. With the consideration of environmental risk and seasonal biomass supply, Fattahi et al. [19] explore the planning of a biomass power generation system. Xu et al. [20] incorporate oil-gas recovery into the green vehicle routing problem in refined oil distribution. Niu et al. [8] investigate a manufacturer's power strategy based on a supply chain consisting of a wind power supplier, a regular power supplier, and a green manufacturer. They further examine the impact of power strategy on environmental and social welfare. Xu et al. [21] study gasoline stations' replenishment strategies considering overlapping time windows of multiple tanks. Rajabzadeh and Wiens [15] analyze manufacturer's power strategy from renewable and fossil fuel power plants in a cooperative and non-cooperative environment, focusing on the resilience and sustainability of the energy supply chain. Xu et al. [22] propose a sustainable development benchmarking framework for energy firms in the oil and gas industry. Our research is related to the works conducted by Niu et al. [8] and Rajabzadeh and Wiens [15]. However, unlike these studies, which focus on the power strategy of a single manufacturer, we examine the equilibrium power strategies of two competing manufacturers with different market positions. Our analysis assesses overall profitability and environmental performance, indicating that using marine energy may have adverse environmental effects.

This study is also closely related to the literature on sustainable operations. Zhu et al. [23] indicate that supply chain and consumer pressures can compel manufacturers to adopt green practices. Bai and Sarkis [24] propose a method to assess supplier selection based on sustainability factors. Zhang et al. [25] explore the role of managers in translating external pressures into corporate energy efficiency practices. Chen and Chen [26] investigate the relationship between energy use and carbon emissions. In view of the unstable nature of wind power generation, Ding et al. [27] explore the strategic choices of wind power integration under different conditions. Dong et al. [28] investigate the supply chain performance and environmental impact under different investment entities that can invest in green product development. Shen et al. [29] develop a game-theoretic model to investigate the impact of selling green and non-green products in a supply chain on consumer surplus, the environment, and social welfare. Chen et al. [30] proposed a methodology to unify the interpretation of urban carbon footprints. Further, Chen et al. [31] assess and compare the carbon emissions of different cities in different countries with a view to supporting decision-making on carbon neutrality. Shen et al. [32] examine the impact of green technology adoption and environmental taxes on the textiles and apparel supply chain. Zhou et al. [33] analyze the rebound effect, where energy efficiency improvements lead to increased energy consumption in China's manufacturing subsectors. For industrial parks using multiple energy sources, Hui et al. [34] propose a method to portray their multi-energy adjustment capability. Zhang et al. [35] explore future fossil fuel phase-out pathways in China. Focusing on the relationship between urban spatial structure and commuting emissions, Zhang et al. [36] find that polycentric structures have lower carbon emissions.

Many studies have also focused on the environmental impacts of renewable energy such as solar, wind, and marine energy. For example, Aflaki and Netessine [37] analyze an electricity supplier's incentives to invest in renewable energy capacity. Salvador et al. [38] assess the challenges and problems for offshore marine energy facilities in Spain. Hoang et al. [39] provide an in-depth analysis of the integration of renewable energy forms into city energy systems based on techno-economic criteria. Rahman et al. [40] explore the environmental impact of renewable energy from the perspective of power plants. Theodora and Piperis [41] explore development prospects for marine energy and identify key issues for sustainable energy policies. Jamali et al. [42] analyze energy procurement and digitalization strategies in the industrial sector using renewable energy. Cui and Zhao [43] provide a comprehensive review of the environmental implications of marine marine energy technology. Xiao et al. [14] examine how the virtual power plant with risk-seeking can balance potential high profits and extreme losses. Compared to the previous literature, this study is related to the works like Chen and Chen [26], Ding et al. [27], Hui et al. [34] and Xiao et al. [14], considers the supply instability of renewable energy, but focuses specifically on the power strategies of two competing manufacturers. Unlike Jamali et al. [42], who examine choices among different renewable energy suppliers, our study involves two competing manufacturers who can choose energy from either a traditional fossil fuel power supplier or a marine energy supplier, resulting in four distinct equilibriums. Additionally, differing from the studies by Chen and Chen [26], Chen et al. [30] and Zhang et al. [35], we focus on the environmental impact arising from different power strategy equilibriums. This focus is critical because the instability of marine energy supply and the environmental concerns of consumers can significantly influence the sustainability and economic viability of manufacturers' decisions.

There is a growing literature on demand creation due to the decision-maker's efforts /investments, which is closely related to this work. Works such as Ge et al. [44]; Dong et al. [45]; Hu et al. [46]; Niu et al. [47]; Niu et al. [48]; Niu et al. [49] have investigated demand creation induced by R&D investment, sustainable investment, innovation, and quality promoting effort. Ge et al. [44] examine the motivations of two firms in a supply chain to collaborate on R&D investment. Dong et al. [45] study the retailer's order quantity and the manufacturer's sustainability investment in a decentralized supply chain, and further identify how the different contracts coordinate the supply chain. Hu et al. [46] reveal that the impact of potential innovation spillovers may make outsourcing manufacturing to the rival beneficial for the innovator. Niu et al. [47] examine the supply chain members' investments in quality promotion under different procurement structures and the preferences for procurement cooperation. Niu et al. [48] investigate the impact of market saturation and consumer environmental awareness on firms' carbon reduction efforts. Niu et al. [49] investigate how developing countries can induce the multinational firm to source locally by adjusting tariff and improving the carbon emission reduction efficiency of domestic manufacturers. Similar to Dong et al. [45] and Niu et al. [49], our research acknowledges the influence of consumers' environmental concerns on demand creation. However, what sets our paper apart is the inclusion of additional factors such as supplier's pricing dynamics, downstream competition, and supply instability. We aim to analyze the combined impact of these factors alongside demand creation on the manufacturers' power strategies. Understanding these dynamics is essential for developing robust power strategies that balance profitability with environmental sustainability in a competitive market.

In summary, this paper captures consumer environmental concerns and marine energy supply instability, two key factors that realistically influence manufacturers' energy strategies, and analyzes manufacturers' equilibrium energy strategies in a competitive environment. In addition, this paper also analyses the environmental performance under different power strategy combinations, providing effective managerial insights for the government and manufacturers. To ensure clarity and brevity, we present Table 1 to compare this work with the most relevant studies.

3. Model setting

Consider two competing manufacturers, m_1 and m_2 (denoted by $i \in \{1,2\}$). Typical examples are Tsingtao Brewery and China Resources Beer, which are rivals in the Chinese market. Tsingtao Brewery initiated its transition to green energy early and, by the end of 2023, had 31 factories exclusively powered by renewable sources [12]. At the same time, China Resources Beer is in the initial stages of building its first zero-carbon factory [50]. Therefore, they can choose either a fossil power supplier or a marine energy supplier to obtain power for production. The manufacturers' products are substitutable in the downstream market, so manufacturer i's inverse demand function is:

$p_i = a - q_i - b_i q_j, i,j = 1,2; i \neq j$, where p_i is the market price of the manufacturer i' products, q_i is the quantity, and b_i portrays the effect of the rival's production quantity on the output of manufacturer i's production quantity. To better depict the reality of the situation, Manufacturer 1 is assumed to have a stronger brand advantage, so we have $b_2 = 1$, and $0 < b_1 \leq 1$ [51]. For simplicity, we let $b_1 = b$. Based on the chosen power supplier, the manufacturers' energy strategies are as follows:

1. **Strategy *T***: Electricity is obtained from the fossil power supplier at a power price per unit production quantity w_i, $i \in \{1,2\}$.

Table 1
The position of this work

Literature	energy supply instability	power suppliers' pricing dynamics	environment impact	manufacturers' power strategy
Chen and Chen [26]			✓	
Chen et al. [30]			✓	
Ding et al. [27]	✓		✓	
Dong et al. [45]			✓	
Hui et al. [34]	✓			
Jamali et al. [42]	✓			✓
Niu et al. [8]	✓	✓	✓	
Niu et al. [49]			✓	
Rajabzadeh and Wiens [15]	✓	✓		
Xiao et al. [14]	✓			
Zhang et al. [35]			✓	
This paper	✓	✓	✓	✓

2. **Strategy *M***: Electricity is obtained from the marine energy supplier at a price per unit production quantity w_i, which enables products to be certified as green. Consumers favor environment-friendly products, thus creating extra demand θ.

We abbreviate strategy T and strategy M as T and M, respectively. Let S_i represent the power strategy of Manufacture i, $S_i \in \{T, M\}$. Thus, the manufacturers' power strategy matrix is $(S_1, S_2) \in \{(T,T), (T,M), (M,T), (M,M)\}$. We use superscript $H \in \{TT, TM, MT, MM\}$ to denote each scenario. Fig. 1 illustrates the supply chain structures for these four scenarios.

It is worth noting that the marine energy supplier can not provide enough power in due time because of the marine energy's instability, which directly causes the manufacturer using marine energy power to suffer the instability of the production quantity [1,8,13,14]. It turns out to be that "order q_i, receive ϵq_i (denoted as $\widetilde{q}_i$ below)" [52], random variable $\epsilon \in [0,1]$ (with mean μ and variance σ^2) labels Manufacture i's yield rate [53]. Further, we denote $\lambda = \left(\frac{\mu}{\sigma}\right)^2$ as the technology level [54], with the negative impact of output instability decreasing on λ. Notations and profit functions are summarized in Table 2 and Table 3.

The sequence of events is as follows. First, manufacturers choose the power suppliers respectively. Second, the chosen power supplier(s) determine(s) the unit power price. Third, manufacturers determine their production quantities. The equilibrium outcomes are obtained by backward induction and all the equilibrium outcomes are placed in the Appendix. To avoid trivial cases, $a > \frac{2\theta\lambda}{6\lambda - b\lambda + 8}$ is required.

4. Analysis

We first discuss the sensitivity analysis results in each scenario (i.e., (T,T), (T,M), (M,T), and (M,M)) and then derive the equilibrium power strategies in Section 4.5.

4.1. Benchmark: Scenario (T, T)

Lemma 1. *Sensitivity analysis of the power prices and production quantities in scenario (T,T) w.r.t. b yields: $\frac{\partial w_1^{TT}}{\partial b} < 0$, $\frac{\partial w_2^{TT}}{\partial b} > 0$ and $\frac{\partial q_i^{TT}}{\partial b} < 0$ always holds,* where i $\in \{1,2\}$.

Lemma 1 reveals that, in scenario (T,T), as b increases, Manufacturer 2's product becomes more homogeneous to its rival's. This causes the fossil power supplier to lower the power price for Manufacturer 1 and increase it for Manufacturer 2. The supplier aims to benefit from a larger purchase volume from the more profitable Manufacturer 1 and a higher profit margin from the less profitable Manufacturer 2, despite shrinking demand ($\frac{\partial q_i^{TT}}{\partial b} < 0$). Naturally, the changes in power prices resulting from product homogeneity also impact downstream quantities, we refer to it as *the power price effect*. However, will Manufacturer 1's order quantity really increase as the power price decreases? Lemma 1 gives an interesting answer. That is, for Manufacturer 1, a lower power price does not necessarily induce it to place a larger order size. The reason is as follows. Increased product homogeneity shrinks the overall market potential. That is, the consumer market in which the two manufacturers can compete becomes narrower, leading to smaller manufacturers' order quantities [55]. We refer to this as *the demand shrinking effect.* Obviously, when both manufacturers use fossil power, *the demand shrinking effect* dominates *the power price effect*, resulting in the coexist of $\frac{\partial w_1^{TT}}{\partial b} < 0$ and $\frac{\partial q_1^{TT}}{\partial b} < 0$.

Table 2
Notations

Notations	Definitions
p_i^H	The market price of the manufacturer i's product in Scenario H, where $i \in \{1,2\}$.
q_i^H	Manufacturer i's production quantity in Scenario H, where $i \in \{1,2\}$.
$\widetilde{q}_i$	The actual output of Manufacturer i who uses marine energy, where $i \in \{1,2\}$.
w_i^H	The power price of the manufacturer i in Scenario H, where $i \in \{1,2\}$.
a	The market potential.
θ	Demand creation by eco-friendly consumers.
ϵ	The yield rate of the manufacturer's production under strategy M.
λ	The technology level, $\lambda = \left(\frac{\mu}{\sigma}\right)^2$.
b_i	Homogeneity of rival's products compared with manufacturer i's, $i \in \{1,2\}$.
π_i^H	Manufacturer i's profit in Scenario H.
Subscript	**Players**
T	The fossil power supplier.
M	The marine energy supplier.
i	Designation of the two competing manufacturers, $i \in \{1,2\}$.

Table 3
Profit functions for the two manufacturers

		m_2	
		T	M
m_1	T	$\pi_t^{TT} = q_1^{TT} w_1^{TT} + q_2^{TT} w_2^{TT}$ $\pi_i^{TT} = (p_i^{TT} - w_i^{TT}) q_i^{TT}, i \in \{1,2\}$	$\pi_t^{TM} = q_1^{TM} w_1^{TM}$ $\pi_m^{TM} = \widetilde{q}_2^{TM} w_2^{TM}$ $\pi_1^{TM} = (p_1^{TM} - w_1^{TM}) q_1^{TM}$ $\pi_2^{TM} = (p_2^{TM} - w_2^{TM}) \widetilde{q}_2^{TM}$
	M	$\pi_t^{MT} = \widetilde{q}_1^{MT} w_1^{MT}$ $\pi_m^{MT} = q_2^{MT} w_2^{MT}$ $\pi_1^{MT} = (p_1^{MT} - w_1^{MT}) \widetilde{q}_1^{MT}$ $\pi_2^{MT} = (p_2^{MT} - w_2^{MT}) q_2^{MT}$	$\pi_m^{MM} = \left(\widetilde{q}_1^{MM} w_1^{MM} + \widetilde{q}_2^{MM} w_2^{MM}\right)$ $\pi_i^{MM} = (p_i^{MM} - w_i^{TT}) \widetilde{q}_i^{MM}, i \in \{1,2\}$

4.2. Scenario (M, T)

Lemma 2. *Sensitivity analysis of power prices and production quantities in scenario (M,T) w.r.t. λ and θ yields: $\frac{\partial \left(E\left[w_i^{MT}\right]\right)}{\partial \lambda} < 0$, where $i \in \{1,2\}$;*

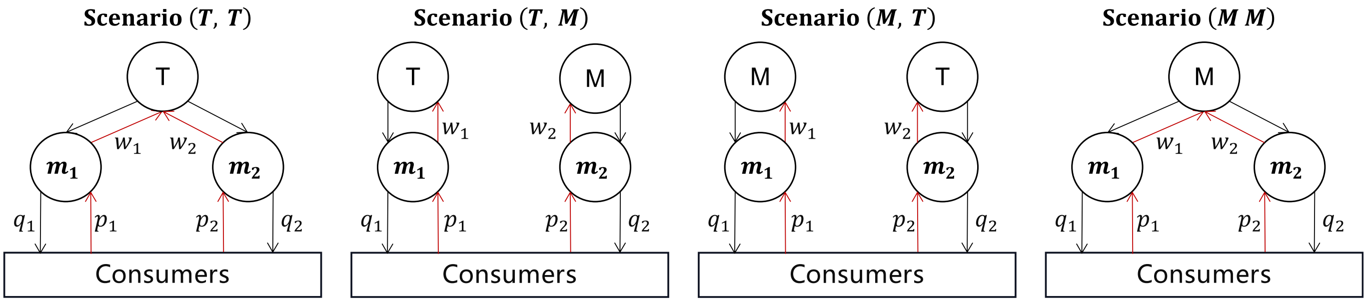

Fig. 1. The illustration of four scenarios.

$\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial\lambda} > 0$ *and* $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial\lambda} < 0$; $\frac{\partial\left(E\left[w_1^{MT}\right]\right)}{\partial\theta} > 0$ *and* $\frac{\partial\left(E\left[w_2^{MT}\right]\right)}{\partial\theta} < 0$; $\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial\theta} > 0$ *and* $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial\theta} < 0$.

When only Manufacturer 1 uses marine energy, as λ increases, both suppliers will lower their power prices. This is because, in scenario (M,T), the power price can be divided into two parts: the risk-free part and the at-risk part. We have:

$$w_1^{MT} = \underbrace{\frac{a(-8+3b)+(-8+b)\theta}{-16+b}}_{\text{the risk–free part}(>0)} + \underbrace{\frac{2b(a(4+b)+4\theta)}{(-16+b)(-16+(-16+b)\lambda)}}_{\text{the at–risk part}(>0)};$$

$$w_2^{MT} = \underbrace{\frac{a(-6+b)+2\theta}{-16+b}}_{\text{the risk–free part}(>0)} + \underbrace{\frac{8(a(4+b)+4\theta)}{(-16+b)(-16+(-16+b)\lambda)}}_{\text{the at–risk part}(>0)}.$$

The risk-free part is independent of λ. The at-risk part, on the other hand, induces a risk cost in the presence of supply instability. Therefore, suppliers respond by curbing planned production through higher power prices. When technological advancements reduce supply instability, the at-risk part will also decrease, leading to $\frac{\partial\left(E\left[w_1^{MT}\right]\right)}{\partial\lambda} < 0$. Considering the marine energy supplier's price cut, the fossil power supplier will also lower w_2^{MT}. However, Manufacturer 2's demand size will decrease despite the fossil power supplier's price cut. The result is the following: On the one hand, lower power price stimulates Manufacturer 1 to produce more. On the other hand, as the marine energy technology level increases, Manufacturer 1's actual output grows, which crowds out Manufacturer 2's demand size.

The impact of θ is intuitive. A large θ indicates that more consumers preferring eco-friendly products are attracted, which will undoubtedly lead to a larger demand size for Manufacturer 1. Considering this, the marine energy supplier will increase the power price to capture downstream advantage. Meanwhile, the fossil power supplier has to lower the power price to stimulate its buyer to place a larger order.

According to Lemma 2, a large θ is better for the manufacturer who uses marine energy. We refer to it as *the marine energy advantage*. As λ increases, this advantage will become more prominent.

Lemma 3. Sensitivity analysis of power prices and production quantities in scenario (M,T) w.r.t. b (yields)

(1) $\frac{\partial\left(E\left[w_i^{MT}\right]\right)}{\partial b} < 0$, where $i \in \{1,2\}$;

(2) $\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial b} > 0$ when (i) $\frac{4a+a\lambda}{3\lambda} < \theta < \theta_1$ and $b < b_1$; (ii) $\theta > \theta_1$; Otherwise, $\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial b} < 0$;

(3) $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial b} > 0$ when (i) $\theta < \theta_2$; (ii) $\theta_2 < \theta < \frac{12a+7a\lambda}{5\lambda}$ and $b < b_2$; Otherwise, $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial b} < 0$.

Lemma 3 shows that b brings different impacts in scenario (M,T). The reasons are as follows. When Manufacturer 1 uses marine energy, competition in the supply chain shifts from purely downstream competition to chain-to-chain competition, which undermines the supplier's monopoly advantage. When competition intensifies as product homogeneity increases (i.e., b increases), suppliers under chain-to-chain competition have no choice but to lower power prices to stimulate their downstream buyers to place a larger order (with hope).

Interestingly, Lemma 3(2) and (3) show that both $\widetilde{q}_1$ and q_2 may increase as competition intensifies. We use Corollary 1 to explain the underlying reasons.

Corollary 1. *The second-order mixed partial derivative of power prices and production quantities in scenario* (M,T) *w.r.t. b and* θ *yields*: (1) $\frac{\partial^2\left(E\left[w_i^{MT}\right]\right)}{\partial b\partial\theta} < 0$, *where* $i \in \{1,2\}$; (2) $\frac{\partial^2\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial b\partial\theta} > 0$ *and* $\frac{\partial^2\left(E\left[q_2^{MT}\right]\right)}{\partial b\partial\theta} < 0$.

Corollary 1 indicates how θ affects *the power price effect* and *the demand shrinking effect*. Note that, the power prices of both the marine energy supplier and the fossil power supplier (i.e., w_1^{MT} and w_2^{MT}) fall with b in scenario (M,T). According to Corollary 1(1), the increase in θ enhances *the power price effect* in scenario (M,T). This is because a large θ puts products that are not produced with marine energy at a competitive disadvantage and thus causes the fossil power supplier to further lower the power price, pushing the upstream into the price war. Consequently, the marine energy supplier, in turn, has to also lower the power price.

According to Corollary 1, $\frac{\partial^2\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial b\partial\theta} > 0$ and $\frac{\partial^2\left(E\left[q_2^{MT}\right]\right)}{\partial b\partial\theta} < 0$ hold. This indicates that a large θ will dampen the impact of *the demand shrinking effect* on Manufacturer 1 while amplifying that on Manufacturer 2.

As a result, a large amount of green-minded consumers for Manufacturer 1 (i.e., $\theta > \theta_1$) will enhance *the marine energy advantage* and amplify *the power price effect.* On the other hand, *the demand shrinking effect* will be suppressed, which renders $\widetilde{q}_1$rise in b. When θ is moderate (i.e., $\frac{4a+a\lambda}{3\lambda} < \theta < \theta_1$), *the power price effect* dominates only when b is small (i.e., $b < b_1$). Otherwise, the cut-throat competition will make *the demand shrinking effect* dominate, and hence $\widetilde{q}_1^{MT}$ falls with b.

In contrast, for Manufacturer 2, although a large θ allows it to benefit from a low power price, this meager benefit cannot cover the disadvantages from the rival's marine energy use. Therefore, only when θ is sufficiently small (i.e., $\theta < \theta_2$), or θ is moderate and b is small (i.e., $\theta_2 < \theta < \frac{12a+7a\lambda}{5\lambda}$ and $b < b_2$), can the benefit from *the power price effect* override these disadvantages, which allows $q_2$rise in b and thus Manufacturer 2 obtains a larger demand size.

4.3. Scenario (T,M)

Lemma 4. *Sensitivity analysis of power prices and production quantities in scenario* (T,M) *w.r.t.* λ *and* θ *yields*: $\frac{\partial\left(E\left[w_i^{TM}\right]\right)}{\partial\lambda} < 0$, *where* $i \in \{1,2\}$; $\frac{\partial\left(E\left[q_1^{TM}\right]\right)}{\partial\lambda} < 0$ *and* $\frac{\partial\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial\lambda} > 0$; $\frac{\partial\left(E\left[w_1^{TM}\right]\right)}{\partial\theta} < 0$ *and* $\frac{\partial\left(E\left[w_2^{TM}\right]\right)}{\partial\theta} > 0$; $\frac{\partial\left(E\left[q_1^{TM}\right]\right)}{\partial\theta} < 0$ *and* $\frac{\partial\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial\theta} > 0$.

Similar to Lemma 2, Lemma 4 highlights the benefit from the marine energy advantage. The difference is that in scenario (T,M), the benefit accrues to Manufacturer 2. Given the analogous mechanism to Lemma 2, we omit the explanation for Lemma 4 and focus on the effect of b (instead)

Lemma 5. *Sensitivity analysis of power prices and production quantities in scenario* (T,M) *w.r.t. b yields*: $\frac{\partial\left(E\left[w_i^{TM}\right]\right)}{\partial b} < 0$, *where* $i \in \{1,2\}$; $\frac{\partial\left(E\left[q_1^{TM}\right]\right)}{\partial b} < 0$ *and* $\frac{\partial\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial b} > 0$.

Lemma 5 reveals that the two suppliers are still locked in a price war in the chain-to-chain competition just like in scenario (M,T). Differently, Lemma 5 also shows that the variation of two manufacturers' production quantities with b is no longer non-monotonic in scenario (T,M). The reason is as follows: When Manufacturer 2 uses marine energy, on the one hand, it benefits from *the marine energy advantage* and *the power price effect*; On the other hand, the increasing b narrows the gap between its products and its rival's. As a result, Manufacturer 2's demand size increases in b, which squeezes its rival's demand size, indicating intensified market competition.

Corollary 2. *The second-order mixed partial derivative of power prices and production quantities in scenario* (T,M) *w.r.t. b and* θ *yields*: $\frac{\partial^2\left(E\left[w_i^{TM}\right]\right)}{\partial b\partial\theta} < 0$, *where* $i \in \{1,2\}$; $\frac{\partial^2\left(E\left[q_1^{TM}\right]\right)}{\partial b\partial\theta} < 0$ *and* $\frac{\partial^2\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial b\partial\theta} > 0$.

Similar to Corollary 1, Corollary 2 indicates that θ amplifies *the power price effect* in scenario (T, M). In addition, Corollary 2 further shows that *the marine energy advantage* will benefit the marine user (i.e., Manufacturer 2), especially when competition is fierce.

4.4. Scenario (M, M)

Lemma 6. *Sensitivity analysis of power prices and production quantities in scenario* (M, M) *w.r.t.* λ *and* θ *yields:* w_i^{MM} *is independent of* λ; $\frac{\partial\left(E\left[\widetilde{q}_i^{MM}\right]\right)}{\partial\lambda} > 0$; $\frac{\partial\left(E\left[w_i^{MM}\right]\right)}{\partial\theta} > 0$; $\frac{\partial\left(E\left[\widetilde{q}_i^{MM}\right]\right)}{\partial\theta} > 0$, *where* $i \in \{1, 2\}$.

Lemma 6 reveals how *the marine energy advantage* works in scenario (M, M).We surprisingly find that the marine energy supplier will only raise power prices as θ increases, but independent of λ. One reason is that when both Manufacturer 1 and Manufacturer 2 use marine energy, the supplier is in a monopoly position, so all the supply instability risk is transferred to the downstream buyers.

Lemma 7. *Sensitivity analysis of power prices and production quantities in scenario* (M, M) *w.r.t.* b *yields:* $\frac{\partial\left(E\left[w_1^{MM}\right]\right)}{\partial b} < 0$, $\frac{\partial\left(E\left[w_2^{MM}\right]\right)}{\partial b} > 0$ *and* $\frac{\partial\left(E\left[\widetilde{q}_i^{MM}\right]\right)}{\partial b} < 0$, *where* $i \in \{1, 2\}$.

When both Manufacturer 1 and Manufacturer 2 use marine energy, the supply chain structure is similar to that in scenario (T, T), i.e., one-to-two structure. Recall Lemma 1, where *the power price effect* and *the demand shrinking effect* will influence w_i and $\widetilde{q}_i$. We find Lemma 7 is nearly identical to Lemma1, so we omit the detailed interpretations.

4.5. Analysis of the equilibrium results

Observation 1. Pure equilibrium $(M,\ M)$, (T, M) and mixed-equilibrium $(M, T)/(T, M)$ may arise, depending on the demand creation due to consumers' environmental concern (i.e., θ). and the product homogeneity that indexes market competition intensity. See Fig. 2 for the illustration.

The horizontal axis is b and the vertical axis is θ. Clearly, as θ becomes larger, the equilibrium strategy paths of Manufacturer 1 and Manufacturer 2 are as follows: (T, T)→(M, T)→the mixed equilibrium of $(M, T)/(T, M)$→(T, M)→(M, M). It is evident that increased consumer preference for green products and advancements in technology level will encourage manufacturers to favor marine energy. This is consistent with real-world observations: the European Union has identified green education as a key focus area in EU education [56], and invested in marine energy startups in the United States grew fivefold from 2018 to 2023 [57].

To interpret the underlying driving forces of equilibrium strategy paths, we will first analyze each equilibrium individually.

Proposition 1. (T, T) *is the unique equilibrium when one of the following conditions is satisfied*:

$\lambda \le \lambda_1, \theta \le \theta_3$ *and* $b < min[1, b_3]$;

$\lambda_1 < \lambda < \lambda_2, (i)\theta < \theta_4; (ii)\theta_4 < \theta < \theta_5$ *and* $(b < b_3$ *or* $b > b_4); (iii)\theta_5 \le \theta < \theta_3$ *and* $b < b_3$;

$\lambda_2 < \lambda < \lambda_3, (i)\theta < \theta_4; (ii)\theta_4 < \theta < \theta_3$ *and* $(b < b_3$ *or* $b > b_4)); (iii)\theta_3 \le \theta < \theta_5$ *and* $b > b_4$;

$\lambda_3 \le \lambda < \lambda_4, (i)\theta < \theta_3$ *and* $(b < b_3$ *or* $b > b_5)); (ii)\theta_3 \le \theta < \theta_5$ *and* $b > b_4$;

$\lambda_4 \le \lambda < \lambda_5, \theta < \theta_5$ *and* $b > b_4$.

Proposition 1 indicates that the two manufacturers' power strategy is mostly sensitive to the marine energy stability level, competition intensity and demand creation by eco-friendly consumers (See Fig. 3). In general, Proposition 1 indicates that when both λ and θ are not large will the two manufacturers stick to using fossil power. Consider an extreme case where the marine energy supplier is stable, that is, λ is sufficiently high so that $\epsilon \to 1$. The manufacturers that use marine energy will undoubtedly benefit from green-minded consumers due to *the marine energy advantage*. This benefit will override the downside of marine energy supply instability. Therefore, (T, T) equilibrium only appears when both λ and θ are not large, where *the power price effect* and *the demand shrinking effect* become important driving forces that hedge *the marine energy advantage*.

It's worth noting that, there exists a win-win situation where one manufacturer (i.e., the marine energy user) benefits from the enhanced *marine energy advantage* and *the power price effect* (see Corollary 1), and the other also benefits from *the power price effect*. Thus, (T, T) equilibrium holds when $b < b_3$ and $b > b_4$ (see Proposition 1(2)(ii), Proposition 1(3)(ii), Proposition 1(4)(i)). The reasons are as follows. As θ is relatively small, though Manufacturer 1 has the incentive to use marine energy, the cost due to supply instability will be too high which could not be covered by boomed demand given a small θ. Manufacturer 2, as the weaker party in terms of brand competitiveness, also has no incentive to use marine energy so as to benefit from product heterogeneity and softened market competition (i.e., $b < b_3$). When b is large, e.g., $b \to 1$,

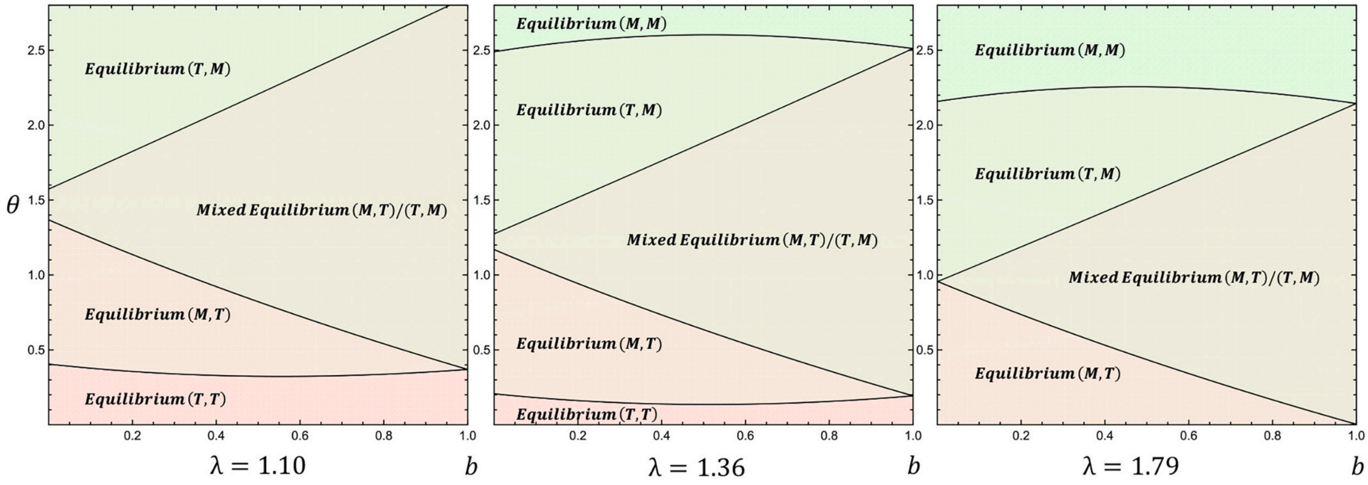

Fig. 2. The two competing manufacturers' equilibrium power strategies ($a = 3.85$).

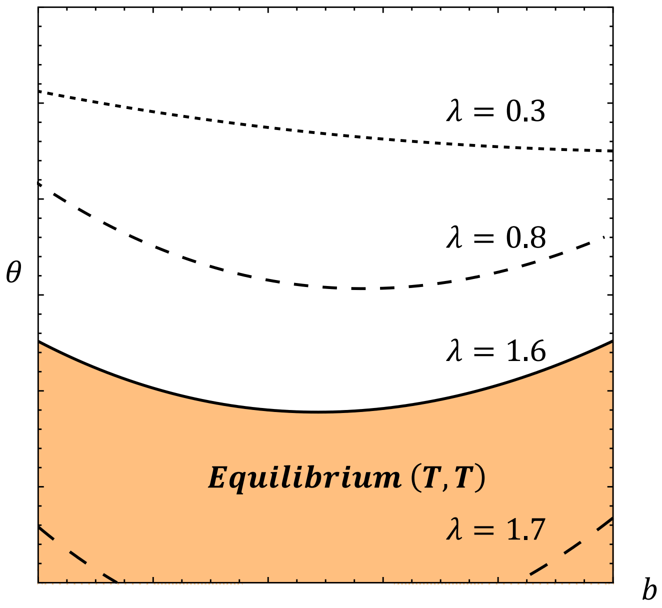

Fig. 3. The impact of θ, b and λ in Equilibrium (T, T) $(a = 3.85)$.

product homogeneity is enhanced and market competition is intensified. On the one hand, if $\lambda < \lambda_5$, the manufacturer using marine energy will suffer from supply instability. On the other hand, fierce competition will highlight the negative impact of such supply instability. So we have the equilibrium (T, T). As θ further increases, the demand created by green-minded consumers actually softens market competition. If θ is not very large, then the two manufacturers should adopt an asymmetric strategy $(T, M)/(M, T)$ for channel coordination. If θ is sufficiently large, then (M, M) will arise as the pure equilibrium.

Regarding the impact of λ, we find that as λ increases, *the marine energy advantage* is significant and can overcome the negative impact of supply instability when b is small. However, a large λ guarantees a large actual number of products for the marine energy user (see Lemma 2, Lemma 4), and further intensifies the competition, which can not be mitigated by limited demand creation (i.e., $\theta < \theta_5$). Therefore, the manufacturer still prefers (T, T) when $b > b_4$.

Proposition 2. There are three asymmetric equilibriums:

1. (M, T) is the equilibrium when $max[0, \theta_4, \theta_5] < \theta < min[\theta_6, \theta_7]$ and $max[0, b_3, b_5] < b < min[b_4, b_6]$;
2. (T, M) is the equilibrium when $max[\theta_7, \theta_8] < \theta < \theta_9$ and $max[0, b_6, b_7] < b < min[b_5, b_8]$;
3. (M, T) or (T, M) is the mixed equilibrium when $max[0, \theta_5] < \theta < min[\theta_9, \theta_{10}]$ and $max[0, b_5, b_6] < b < 1$.

Proposition 2 elaborates on the win-win situation mentioned in Proposition 1. That is, as a more brand-competitive party, when θ is not very large, Manufacturer 1 would switch to using marine energy to benefit from *the marine energy advantage*. Meanwhile, Manufacturer 2 can benefit from the lower power price due to *the power price effect* in scenario (M, T) (see Lemma 5, Corollary 1). As θ and b increase, Manufacturer 2's incentive to use marine energy will also be enhanced. Note that, the benefit of *the marine energy advantage* is not sufficient to make two manufacturers better when they use marine energy simultaneously. As a result, Manufacturer 1 cedes *the marine energy advantage* and benefits from the lower power price, even though its demand may shrink in scenario (T, M). Otherwise, it will be hurt by *the demand shrinking effect* (see Lemma 4, Lemma 5, Lemma 6). It is worth noting that the mixed equilibrium $(T, M)/(M, T)$ holds when b is large. This is because the two manufacturers become homogeneous, and intensified competition drives either Manufacturer 1 or Manufacturer 2 to scramble for *the marine energy advantage* rather than strengthening their homogeneity by choosing the same power strategy.

Proposition 3. *(M, M) is the equilibrium when one of the following conditions is satisfied:*

$\lambda < \lambda_1, \theta > \theta_{11}$ *and* $b < min[1, b_7]$;

$\lambda_1 < \lambda < \lambda_2$, $(i)\theta_{11} < \theta \leq \theta_9$ *and* $b < b_7$, $(ii)\theta_9 < \theta < \theta_{10}$ *and* $(b < b_7$ *or* $b > b_8)$, $(iii)\theta > \theta_{10}$;

$\lambda > \lambda_2$, $(\mathrm{i})\theta_9 < \theta \leq \theta_{11}$ and $b > b_8$, $(\mathrm{ii})\theta_{11} < \theta < \theta_{10}$ and $(b < b_7$ or $b > b_8)$, $(\mathrm{iii})\theta > \theta_{10}$.

Proposition 3 indicates that both manufacturers will use marine energy power when θ is large enough because the benefit of *the marine energy advantage* covers the all downsides (See Fig. 4). Given a small θ, interesting findings emerge. Equilibrium (M, M) holds only when b is either small or large. The reasons are as follows. As discussed in Proposition 2, a small b leads to a minimal *demand shrinking effect*, so Manufacturer 1 tends to benefit from *the marine energy advantage* when a relatively large θ attracts many green-minded consumers. If b is larger, Manufacturer 1's demand is further squeezed in scenario (T, M), especially when θ is large (see Lemma 5, Corollary 2). Therefore, Manufacturer 1 has to use marine energy to attract green-minded consumers and then equilibrium (M, M) (holds)

5. The environmental performance

In this section, we will analyze the environmental performance in the four equilibriums. Denote the average unit Scope 1 carbon emission as E, then the environmental performances [58] in four scenarios become:

$$EI^{TT} = E_f q_1 + E_f q_2 + E(q_1 + q_2);\ EI^{MT} = E_m \widetilde{q}_1 + E_f q_2 + E\left(\widetilde{q}_1 + q_2\right);$$

$$EI^{TM} = E_f q_1 + E_m \widetilde{q}_2 + E\left(q_1 + \widetilde{q}_2\right);\ EI^{MM} = E_m \widetilde{q}_1 + E_m \widetilde{q}_2 + E\left(\widetilde{q}_1 + \widetilde{q}_2\right).$$

We find that all the findings and managerial insights are unchanged, because mathematically the manufacturers' carbon emission changes from $E_f \rightarrow E'_f = \left(E_f + E\right)$ and $E_m \rightarrow E'_m = \left(E_m + E\right)$. Therefore, to better gain managerial insights into manufacturers' power strategy decisions, we focus on Scope 2 carbon emission in the main model, i.e., the indirect

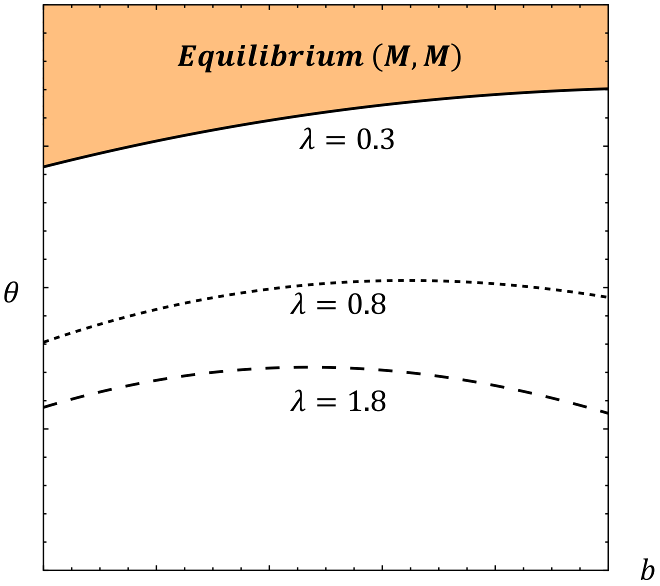

Fig. 4. The impact of θ, b and λ in Equilibrium (M, M) $(a = 3.85)$.

emission from manufacturers' energy sources [26]. Marine energy generation does not generate carbon emissions, thus the carbon factor for Scope 2 is 0 [59]. We omit the Scope 1 carbon emission (i.e., $E = 0$), but if $E > 0$ and/or $E_m > 0$, then the findings can be found in Section 7.3. It is evident that a smaller value of EI^H indicates better environmental performance.

Proposition 4. The environment of the four equilibriums is $\mathrm{EI}^{\mathrm{TT}} > \mathrm{EI}^{\mathrm{TM}} > \mathrm{EI}^{\mathrm{MT}} > \mathrm{EI}^{\mathrm{MM}}$.

Proposition 4 reveals a surprising result: The environmental performance does not necessarily improve as *the marine energy advantage* increases. As discussed in Proposition 2, when θ increases, (M, T) equilibrium shifts to (T, M) equilibrium. While this is a rational choice from the perspective of the manufacturers' profits, it is not beneficial for the environment. That is, as the more brand-competitive party, Manufacturer 1 has a larger demand size, resulting in higher production carbon emissions. Therefore, the adoption of marine energy by Manufacturer 1 rather than Manufacturer 2 can be more effective in reducing carbon emissions.

Proposition 4 provides some interesting managerial insights. From the government's perspective, promoting the use of marine energy is best for the environment, but manufacturers' use of marine energy is often driven by profit maximization. As a result, while the government wants to promote marine energy through green education and/or other methods, this may lead to manufacturers' equilibrium strategies falling into (T, M) (see Observation 1), and thus make the environmental performance worse. Therefore, the government should achieve convergence between the government's goals and manufacturers' objectives through carbon mitigation policies (e.g., encouraging leading companies to adopt marine energy by penalties or subsidies), so as to avoid the equilibrium (T, M).

6. Numerical study

In this section, we focus on Tsingtao Brewery, a well-known Chinese brand mentioned in the Introduction as a renewable energy user. According to the 2023 ESG report [12], all Tsingtao Brewery factories in Shandong use 100% renewable energy for production. China Resources Beer, with assets of nearly $10 billion, is Tsingtao's main competitor in China [50].

We obtain sales information from the 2019–2023 annual reports of Tsingtao Brewery and China Resources Beer [60,61], based on which the values of a and b are derived from the expressions for equilibrium profits by backcasting (the market potential is estimated as $a = 245.87$ and their products are of high homogeneity $b = 0.73$). As market conditions can be volatile in four scenarios, we adjust the value of $b \in \{0.25, 0.95\}$ to analyze its impact accordingly. Further, a survey of consumers by PricewaterhouseCoopers [62] reveals that consumers are more likely to buy the sustainable product and the impact of the high valuation of the sustainable product by eco-friendly consumers on its market potential is around 10% (compared to the regular product). Therefore, we let the demand creation by eco-friendly consumers $\theta = 10\%a$, that is, $\theta = 24.59$. We also consider $\theta \in \{10.00, 35.00\}$ to see the impact on the results. Taking Jiangxia Tidal Power Station (the largest marine energy power station in China) as an example, we calculate its capacity factor to measure the stability of marine energy [63]. We estimate the mean and variance as $\mu = 22.41\%$ and $\sigma^2 = 0.0018$. Further, we obtain $\lambda = 29.08$, which is scaled to 2.91 for consistency with the main body. In a similar vein, we adjust the value of $\lambda \in \{1, 5\}$. See Table 4, Table 5, and Table 6 for all estimated parameters.

Table 4, Table 5, and Table 6 show how manufacturers' performances change with b, θ, and λ, and highlight the impact of *the marine energy advantage*, *the power price effect* and *the demand shrinking effect*. Focusing on the bolded profit differences in the above tables, we can derive the manufacturers' equilibrium strategies. When θ and λ are both small, scenario (T, T) is the only equilibrium such that both manufacturers have positive profit differences. As λ increases, scenario (T, T) can not be the equilibrium. Furthermore, given a relatively large θ, we find that the equilibrium strategies of the two manufacturers are more likely to shift from the (M, T) equilibrium to the mixed equilibrium as b increases. These findings are consistent with Observation 1 in the main body (see Fig. 2). However, we find that (M, M) does not occur. The main reason is that consumer preference for sustainable products is not high (PwC, [62]), which also explains why not every manufacturer is willing to use marine energy despite its advantages in practice. For example, Zhujiang Brewery does not use 100% renewable energy such as marine energy. In addition, China Resources Beer mentioned above, has only committed to renewable energy production without fully achieving it. Therefore, while the government is committed to improving marine energy technologies, it is also important to raise consumers' environmental awareness to increase their preference for sustainable products. In other words, a two-pronged approach to technology development and green education can better drive manufacturers to use marine energy.

Table 4
Comparison of the performances of the manufacturers ($b = 0.25$)

	$\lambda = 1.00$			$\lambda = 2.91$			$\lambda = 5.00$		
θ	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**
$b = 0.25$									
π_1^{TT} (¥M)	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27
π_2^{TT} (¥M)	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27	2193.27
π_1^{MT} (¥M)	1892.00	2128.76	2306.22	2881.43	3242.20	3512.61	3253.71	3661.18	3966.59
π_2^{MT} (¥M)	2984.64	2933.03	2896.49	2608.99	2535.94	2484.46	2474.57	2394.43	2338.05
π_1^{TM} (¥M)	3705.28	3690.86	3680.58	3666.34	3644.57	3629.08	3651.58	3627.08	3609.65
π_2^{TM} (¥M)	1226.29	1418.26	1563.77	1860.07	2152.02	2373.33	2097.26	2426.76	2676.55
π_1^{MM} (¥M)	1187.65	1326.96	1431.07	1767.81	1975.17	2130.14	1979.42	2211.60	2385.12
π_2^{MM} (¥M)	1187.65	1326.96	1431.07	1767.81	1975.17	2130.14	1979.42	2211.60	2385.12
$\pi_1^{TT} - \pi_1^{MT}$	**301.27**	**64.51**	−112.95	−688.16	−1048.93	−1319.34	−1060.44	−1467.91	−1773.32
$\pi_2^{TT} - \pi_2^{TM}$	**966.98**	**775.01**	629.50	333.20	41.25	−180.06	96.01	−233.49	−483.28
$\pi_1^{MT} - \pi_1^{TT}$	−301.27	−64.51	**112.95**	**688.16**	**1048.93**	**1319.34**	**1060.44**	**1467.91**	1773.32
$\pi_2^{MT} - \pi_2^{MM}$	1796.99	1606.07	**1465.42**	**841.18**	**560.77**	**354.32**	**495.15**	**182.83**	−47.07
$\pi_1^{TM} - \pi_1^{MM}$	2517.63	2363.90	2249.51	1898.53	1669.40	1498.94	1672.16	**1415.48**	**1224.53**
$\pi_2^{TM} - \pi_2^{TT}$	−966.98	−775.01	−629.50	−333.20	−41.25	180.06	−96.01	**233.49**	**483.28**
$\pi_1^{MM} - \pi_1^{TM}$	−2517.63	−2363.90	−2249.51	−1898.53	−1669.40	−1498.94	−1672.16	−1415.48	−1224.53
$\pi_2^{MM} - \pi_2^{MT}$	−1796.99	−1606.07	−1465.42	−841.18	−560.77	−354.32	−495.15	−182.83	47.07

Table 5
Comparison of the performances of the manufacturers ($b = 0.73$)

	$\lambda = 1.00$			$\lambda = 2.91$			$\lambda = 5.00$		
θ	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**
$b = 0.73$									
π_1^{TT}(¥M)	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20
π_2^{TT}(¥M)	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20	1841.20
π_1^{MT}(¥M)	1574.44	1802.10	1973.93	2502.12	2865.94	3140.62	2872.03	3290.52	3606.50
π_2^{MT}(¥M)	3255.42	3197.10	3155.81	2956.29	2868.55	2806.75	2839.74	2741.32	2672.16
π_1^{TM}(¥M)	3538.76	3494.31	3462.76	3389.69	3320.94	3272.32	3329.34	3251.33	3196.22
π_2^{TM}(¥M)	1323.18	1532.52	1691.28	2091.57	2425.26	2678.44	2395.89	2779.35	3070.35
π_1^{MM}(¥M)	997.01	1113.95	1201.36	1484.04	1658.11	1788.21	1661.68	1856.59	2002.26
π_2^{MM}(¥M)	997.01	1113.95	1201.36	1484.04	1658.11	1788.21	1661.68	1856.59	2002.26
$\pi_1^{TT} - \pi_1^{MT}$	**266.76**	**39.10**	−132.73	−660.92	−1024.74	−1299.42	−1030.83	−1449.32	−1765.30
$\pi_2^{TT} - \pi_2^{TM}$	**518.02**	**308.68**	149.92	−250.37	−584.06	−837.24	−554.69	−938.15	−1229.15
$\pi_1^{MT} - \pi_1^{TT}$	−266.76	−39.10	**132.73**	**660.92**	**1024.74**	**1299.42**	**1030.83**	**1449.32**	**1765.30**
$\pi_2^{MT} - \pi_2^{MM}$	2258.41	2083.15	**1954.45**	**1472.25**	**1210.44**	**1018.54**	**1178.06**	**884.73**	**669.90**
$\pi_1^{TM} - \pi_1^{MM}$	2541.75	2380.36	2261.40	**1905.65**	**1662.83**	**1484.11**	**1667.66**	**1394.74**	**1193.96**
$\pi_2^{TM} - \pi_2^{TT}$	−518.02	−308.68	−149.92	**250.37**	**584.06**	**837.24**	**554.69**	**938.15**	**1229.15**
$\pi_1^{MM} - \pi_1^{TM}$	−2541.75	−2380.36	−2261.40	−1905.65	−1662.83	−1484.11	−1667.66	−1394.74	−1193.96
$\pi_2^{MM} - \pi_2^{MT}$	−2258.41	−2083.15	−1954.45	−1472.25	−1210.44	−1018.54	−1178.06	−884.73	−669.90

Table 6
Comparison of the performances of the manufacturers ($b = 0.95$)

	$\lambda = 1.00$			$\lambda = 2.91$			$\lambda = 5.00$		
θ	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**	**10.00**	**24.59**	**35.00**
$b = 0.95$									
π_1^{TT}(¥M)	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56
π_2^{TT}(¥M)	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56	1707.56
π_1^{MT}(¥M)	1420.12	1642.00	1810.16	2297.16	2659.90	2934.97	2655.69	3086.35	3396.14
π_2^{MT}(¥M)	3394.84	3332.99	3289.21	3145.81	3049.80	2982.21	3043.26	2931.92	2857.75
π_1^{TM}(¥M)	3449.54	3390.30	3348.34	3231.22	3138.74	3073.57	3140.46	3032.94	2961.24
π_2^{TM}(¥M)	1372.63	1590.91	1756.49	2217.12	2573.72	2844.41	2561.72	2984.98	3289.76
π_1^{MM}(¥M)	924.65	1033.10	1114.16	1376.33	1537.76	1658.41	1541.07	1725.91	1856.93
π_2^{MM}(¥M)	924.65	1033.10	1114.16	1376.33	1537.76	1658.41	1541.07	1725.91	1856.93
$\pi_1^{TT} - \pi_1^{MT}$	**287.44**	**65.56**	−102.60	−589.60	−952.34	−1227.41	−948.13	−1378.79	−1688.58
$\pi_2^{TT} - \pi_2^{TM}$	**334.93**	**116.65**	−48.93	−509.56	−866.16	−1136.85	−854.16	−1277.42	−1582.20
$\pi_1^{MT} - \pi_1^{TT}$	−287.44	−65.56	**102.60**	**589.60**	**952.34**	**1227.41**	**948.13**	**1378.79**	**1688.58**
$\pi_2^{MT} - \pi_2^{MM}$	2470.20	2299.89	**2175.05**	**1769.48**	**1512.04**	**1323.80**	**1502.19**	**1206.01**	**1000.82**
$\pi_1^{TM} - \pi_1^{MM}$	2524.90	2357.20	**2234.18**	**1854.89**	**1600.98**	**1415.16**	**1599.39**	**1307.03**	**1104.31**
$\pi_2^{TM} - \pi_2^{TT}$	−334.93	−116.65	**48.93**	**509.56**	**866.16**	**1136.85**	**854.16**	**1277.42**	**1582.20**
$\pi_1^{MM} - \pi_1^{TM}$	−2524.90	−2357.20	−2234.18	−1854.89	−1600.98	−1415.16	−1599.39	−1307.03	−1104.31
$\pi_2^{MM} - \pi_2^{MT}$	−2470.20	−2299.89	−2175.05	−1769.48	−1512.04	−1323.80	−1502.19	−1206.01	−1000.82

7. Discussions and extensions

7.1. *Consumer surplus*

In this section, we will analyze the impact of manufacturers' power strategies on consumer surplus. For notational convenience, we denote overall consumer surplus under the Scenario H as CS^H. Thus, it can be calculated as follows:

$$CS^{TT} = \int_0^{q_1^{TT}} (a - q_1 - bq_2)\mathrm{d}q_1 - p_1q_1 + \int_0^{q_2^{TT}} (a - q_2 - q_1)\mathrm{d}q_2 - p_2q_2;$$

$$CS^{MT} = \int_0^{\widetilde{q}_1^{MT}} \left(a + \theta - \widetilde{q}_1 - bq_2\right)\mathrm{d}\widetilde{q}_1 - p_1\widetilde{q}_1 + \int_0^{q_2^{MT}} (a - q_2 - q_1)\mathrm{d}q_2 - p_2q_2;$$

$$CS^{TM} = \int_0^{q_1^{TM}} (a - q_1 - bq_2)\mathrm{d}q_1 - p_1q_1 + \int_0^{\widetilde{q}_2^{TM}} \left(a + \theta - \widetilde{q}_2 - q_1\right)\mathrm{d}\widetilde{q}_2 - p_2\widetilde{q}_2;$$

$$CS^{MM} = \int_0^{\widetilde{q}_1^{MM}} \left(a + \theta - \widetilde{q}_1 - bq_2\right)\mathrm{d}\widetilde{q}_1 - p_1\widetilde{q}_1 + \int_0^{\widetilde{q}_2^{MM}} \left(a + \theta - \widetilde{q}_2 - q_1\right)\mathrm{d}\widetilde{q}_2 - p_2\widetilde{q}_2.$$

The exact values of CS^H are in the appendix. To better illustrate in which scenario consumers benefit more, we plot Fig. 5 and the colored blocks represent regions where CS^H is the highest.

Examining Fig. 5 reveals that consumers may benefit more in scenario (T,T) or scenario (T,M) when θ is small. If small θ, λ and b are given, consumers benefit more in scenario (T,T). This is attributed to scenario (T,M), where the limited marine energy advantage fails to offset the negative impact of supply instability, resulting in lower total supply compared to scenario (T,T) and thus reducing consumer surplus. As technological advancements occur, the marine energy advantage becomes significant, gradually diminishing and eventually eliminating the region where CS^{TT} is optimal. Additionally, increasing b leads to a similar outcome due to the enhanced demand shrinking effect, resulting in higher prices and reduced total supply in scenario (T,T). On the contrary, in scenario (T,M), consumers can benefit from the lower price and relatively large total demand due to the power price effect.

Similarly, when θ is relatively large, consumers' preferences for different scenarios depend on b. When b is small, the extra demand due to the marine energy advantage leads to a higher overall consumer surplus in scenario (M,M). As b increases, the demand shrinking effect hurts the consumer surplus in scenario (M,M), so the consumers turn to benefit more in scenario (T,M) or scenario (M,T) because of the power

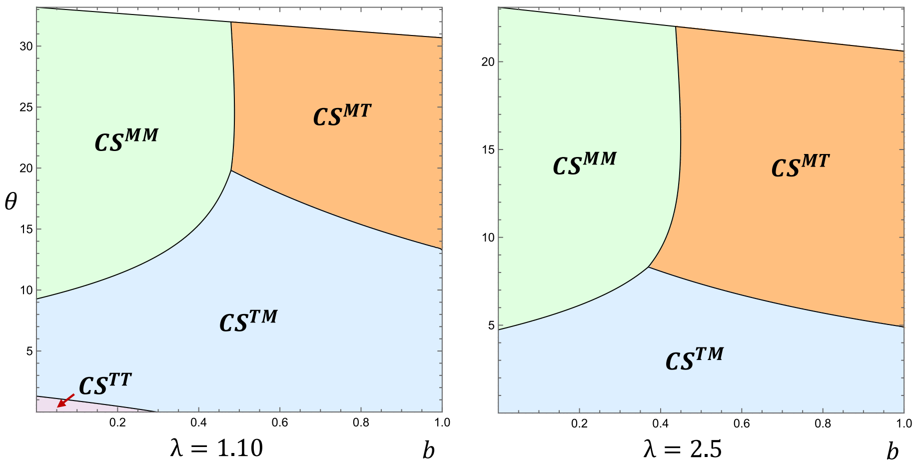

Fig. 5. The impact of λ, θ and b on consumer surplus ($a = 3.85$)

price effect.

Fig. 5 also shows the impact of λ. According to Lemma 2, as λ increases, the marine energy advantage will become more prominent. On the other hand, the power prices charged by the suppliers become lower as λ increases (see Lemma 2, Lemma 4 and Lemma 6), which enlarges the total supply when the manufacturer uses marine energy. Therefore, consumer surplus in scenario (T,T) can not be optimal, so the purple region disappears when λ is large.

7.2. *The impact of the fossil fuel cost*

In practice, the fossil power supplier may incur costs such as fossil fuels cost and/or the penalty to fossil fuels. So we relax the assumption in the main body by considering the fossil fuel power supplier's cost, and derive the profit functions in the four scenarios outlined in Table 7.

Lemma 8. Sensitivity analysis of power prices and production quantities in scenario (T,T), (M,T) and (T,M) w.r.t. c (yields)

(1) $\frac{\partial w_i^{TT}}{\partial c} > 0$ and $\frac{\partial\left(E\left[w_i^H\right]\right)}{\partial c} > 0$, where $i \in \{1,2\}$ and $H \in \{\ TM, MT\}$;

(2) $\frac{\partial q_i^{TT}}{\partial c} < 0$, where $i \in \{1,2\}$; $\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial c} > 0$ and $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial c} < 0$; $\frac{\partial\left(E\left[q_1^{TM}\right]\right)}{\partial c} < 0$ and $\frac{\partial\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial c} > 0$.

Lemma 8 reveals that, on one hand, the fossil power supplier raises the power price as the power generation cost increases, leading to a smaller order quantity for the manufacturer using fossil fuel power (i.e., $\frac{\partial w_i^{TT}}{\partial c} > 0$ and $\frac{\partial q_i^{TT}}{\partial c} < 0$; $\frac{\partial\left(E\left[w_2^{MT}\right]\right)}{\partial c} > 0$ and $\frac{\partial\left(E\left[q_2^{MT}\right]\right)}{\partial c} < 0$; $\frac{\partial\left(E\left[w_1^{TM}\right]\right)}{\partial c} > 0$ and $\frac{\partial\left(E\left[q_1^{TM}\right]\right)}{\partial c} < 0$). In contrast, the manufacturer using marine energy is not directly affected by the fossil power supplier's cost, giving it a cost advantage and a larger order quantity (i.e., $\frac{\partial\left(E\left[\widetilde{q}_1^{MT}\right]\right)}{\partial c} > 0$ and $\frac{\partial\left(E\left[\widetilde{q}_2^{TM}\right]\right)}{\partial c} > 0$). On the other hand, the rising fossil fuel power price mitigates chain-to-chain competition in scenario (M,T) and scenario (T,M) (see Lemma 3 and Lemma 5), incentivizing the marine energy supplier to also raise its power price (i.e., $\frac{\partial\left(E\left[w_1^{MT}\right]\right)}{\partial c} > 0$ and $\frac{\partial\left(E\left[w_2^{TM}\right]\right)}{\partial c} > 0$).

Table 7
Manufacturers' profit functions considering fossil fuel power supplier's cost

		m_2	
		T	M
m_1	T	$\pi_t^{TT} = q_1^{TT}\left(w_1^{TT} - c\right) + q_2^{TT}\left(w_2^{TT} - c\right)$ $\pi_i^{TT} = \left(p_i^{TT} - w_i^{TT}\right)q_i^{TT}, i \in \{1,2\}$	$\pi_t^{TM} = q_1^{TM}\left(w_1^{TM} - c\right)$ $\pi_m^{TM} = \widetilde{q}_2^{TM} w_2^{TM}$ $\pi_1^{TM} = \left(p_1^{TM} - w_1^{TM}\right)q_1^{TM}$ $\pi_2^{TM} = \left(p_2^{TM} - w_2^{TM}\right)\widetilde{q}_2^{TM}$
	M	$\pi_m^{MT} = \widetilde{q}_1^{MT} w_1^{MT}$ $\pi_t^{MT} = q_2^{MT}\left(w_2^{MT} - c\right)$ $\pi_1^{MT} = \left(p_1^{MT} - w_1^{MT}\right)\widetilde{q}_1^{MT}$ $\pi_2^{MT} = \left(p_2^{MT} - w_2^{MT}\right)q_2^{MT}$	$\pi_m^{MM} = \left(\widetilde{q}_1^{MM} w_1^{MM} + \widetilde{q}_2^{MM} w_2^{MM}\right)$ $\pi_i^{MM} = \left(p_i^{MM} - w_i^{TT}\right)\widetilde{q}_i^{MM}, i \in \{1,2\}$

Fig. 6 further illustrates the impact of fossil fuel costs on manufacturers' strategy preferences. It is clear that the increased fossil fuel cost weakens the manufacturer's preference for strategy T. So the manufacturer is driven to use marine energy, where the underlying mechanism is similar to the effect of θ. Moreover, Fig. 6 corroborates the managerial insights presented in Proposition 4. Recall that green education may make the environment worse, which is contrary to the government's goals. We point out that the government could encourage manufacturers to use marine energy through carbon mitigation policies such as penalties. As seen in Fig. 6, appropriate penalties can drive both manufacturers to use marine energy, especially when θ is large, i.e., the region of (M,M) equilibrium expands.

7.3. *The impact of carbon emission from marine energy power*

In Section 5, we only consider Scope 2 carbon emission in four scenarios and thus normalize the carbon emission from marine energy power to zero (i.e., $E_m = 0$). We relax this assumption in this section and regard E_f and E_m as the total carbon emissions (including Scope 1 carbon emission and Scope 2 carbon emission) associated with the manufacturer's power procurement from the fossil power supplier and the marine energy supplier, respectively. Since the analytical solutions are too complex to yield valid comparative results, we examine the impact of carbon emission from marine energy power by an extensive numerical study (see Fig. 7). It is clear that the insights in our main body remain when E_m is small. As the difference between E_m and E_f decreases, the situation becomes complex, where the comparison between the environmental performance in four scenarios is affected by the sophisticated interactions among the marine energy advantage, the demand shrinking effect, and the power price effect.

When E_m approaches E_f, the carbon reduction advantage of using marine energy becomes negligible, so the carbon emissions in different scenarios are primarily influenced by the actual output. When the marine energy advantage is significant, the manufacturer using marine energy tends to have higher output. As a result, in scenarios (M,T), (T,M), and (M,M), the total carbon emissions increase and may even exceed the total emissions in scenario (T,T). Furthermore, since sce-

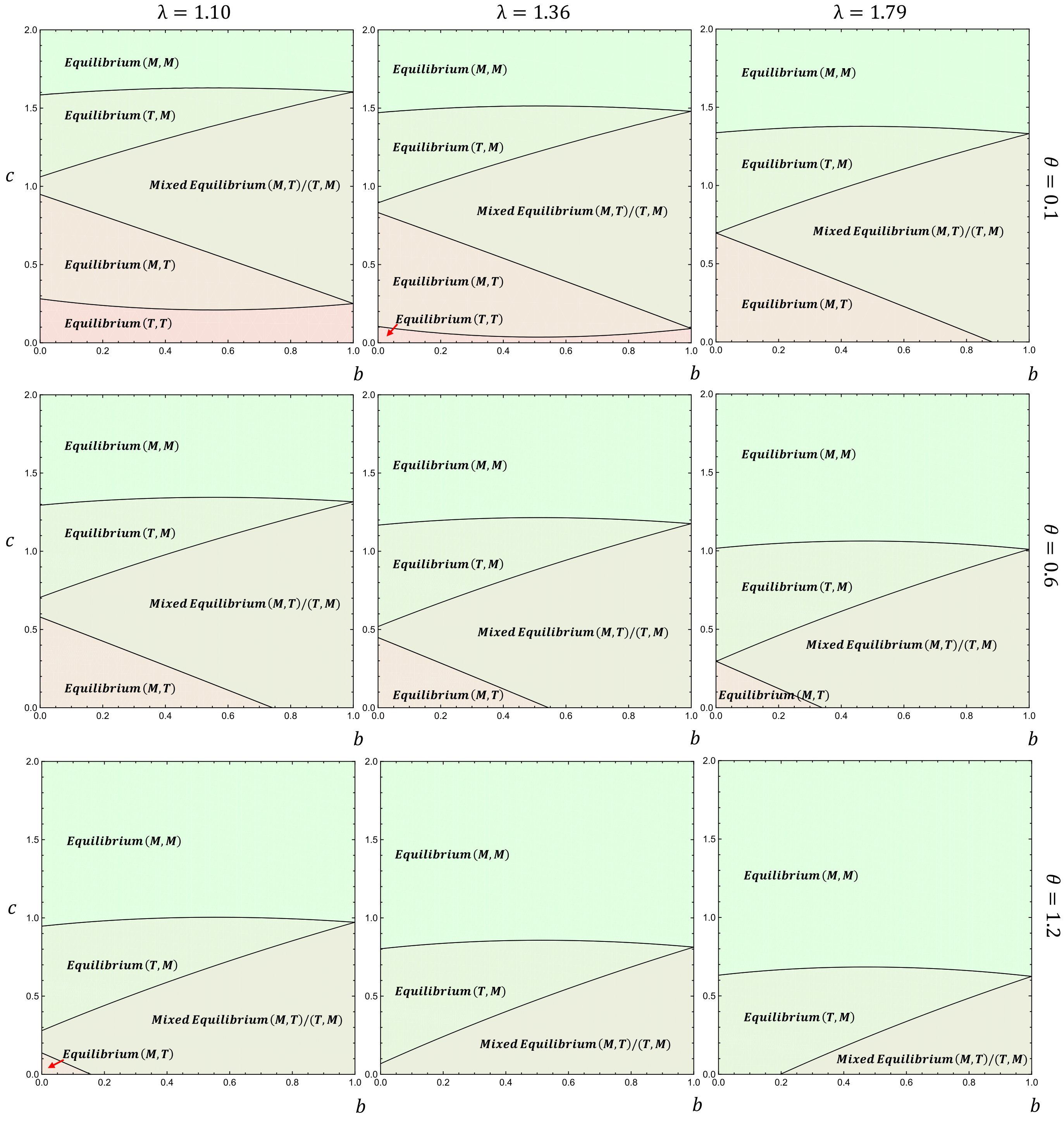

Fig. 6. The impact of c, b, θ and λ on the equilibrium power strategies ($a = 3.85$).

narios (M,T) and (T,M) tend to be equivalent as b increases, the total carbon emissions in scenario (M,T) and (T,M) also tend to converge.

Additionally, the demand shrinking effect has a greater impact in scenarios (T,T) or (M,M), leading to a lower total output. However, in scenarios (M,T) or (T,M), the power price effect mitigates the negative impact of the demand shrinking effect (see Lemma 1, Lemma 3, Lemma 5 and Lemma 7). Therefore, as b increases, the environmental performance of scenarios (M,T) or (T,M) may be worse than that in scenarios (T,T).

8. Conclusion remarks

To promote sustainable societal development, numerous nations are intensifying investments in marine energy and encouraging giant companies to adopt it. While embracing marine energy may enhance a manufacturer's green reputation and attract green-minded consumers, it also introduces challenges related to supply instability. Hence, we formulate the key tradeoffs to analyze how manufacturers navigate the decision between marine power strategy and fossil power strategy.

We find that the use of marine energy can successfully facilitate demand creation, especially when the supply instability is acceptable (i.

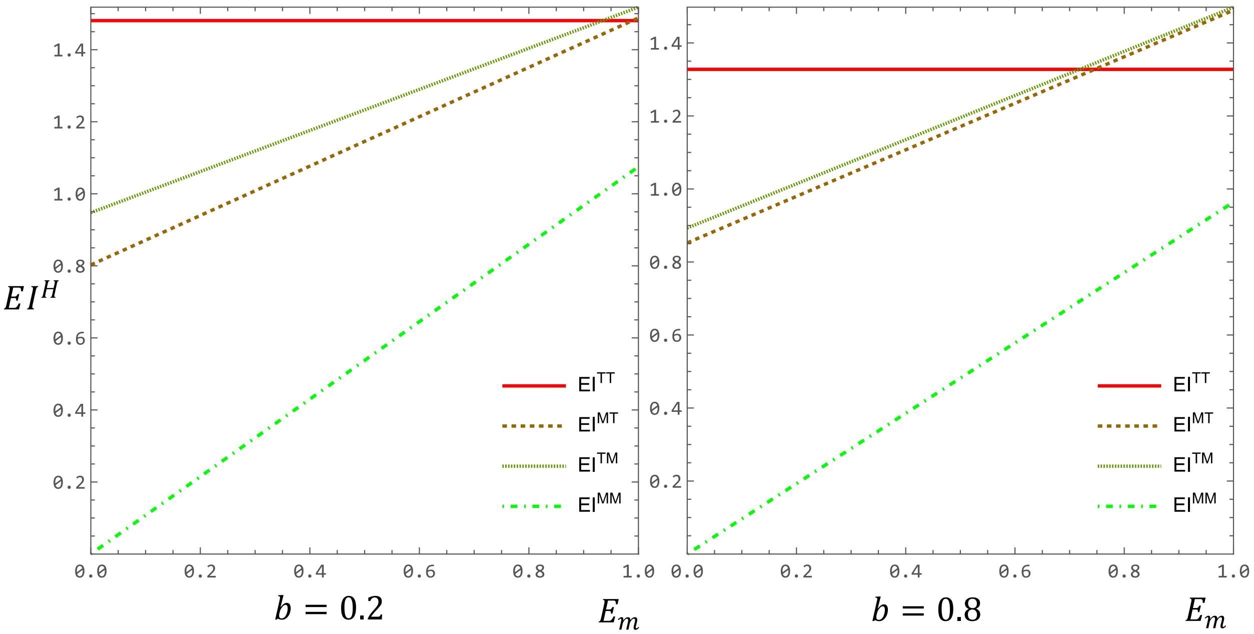

Fig. 7. The impact of b and E_m on the environmental performance ($E_f = 1, \lambda = 1.36, a = 3.85, \theta = 1$).

e., *the marine energy advantage*). However, this may lead to the supplier's price adjustment, thereby influencing the downstream market competition (i.e., *the power price effect*). When two manufacturers' product heterogeneity is not significant (i.e., *the demand shrinking effect* is not dominant), they tend to sustain an asymmetric power strategy equilibrium, to benefit from *the marine energy advantage* and *the power price effect* respectively. This enables a win-win situation. We reveal a surprising result that a smaller *marine energy advantage* might be better for the environmental performance. The reason is that, given insufficient *marine energy advantage*, the more brand-competitive manufacturer with higher carbon emissions will prefer fossil power, benefiting from *the power price effect.*

Our research provides useful insights. For instance, although advances in marine technology and consumer green education by manufacturers and governments can promote the use of marine energy, they may also cause negative environmental impacts. While the government aims to promote the use of marine energy to benefit the environment, manufacturers are driven by profit maximization. This divergence can lead to unintended consequences that manufacturers' optimal equilibrium strategies may be sub-optimal for the environment. To align government and manufacturers' objectives, it is crucial for the government to implement effective carbon mitigation policies, such as penalties for fossil fuels and subsidies for marine energy. Our findings show that such appropriate policies can significantly expand the equilibrium region where both manufacturers use marine energy, leading to better environmental outcomes.

In this study, we have focused on the energy strategies of two unequally positioned manufacturers. Further research can be conducted to examine whether the marine energy supplier and/or the more brand-competitive manufacturer should invest in improving the supply stability of marine energy [64]. It can be also important to design corresponding policies to encourage them to do so. In practice, we observe that the two manufacturers may cooperate with each other in service outsourcing, information sharing, and financial support. For example, the competing manufacturers have the option to jointly invest in the supply and selling of marine. This will create a co-opetition relationship among the suppliers and manufacturers. We predict that interesting findings with respect to their corporation formations and investment efforts can be derived but are beyond the scope of this study.

CRediT authorship contribution statement

Baozhuang Niu: Writing – review & editing, Validation, Supervision, Formal analysis. **Xinhai Deng:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis. **Hongzhi Wang:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

The authors are grateful to the editors and reviewers. This work was supported by the National Natural Science Foundation of China (72125006, 72293564/72293560). Xinhai Deng is the co-first author and Hongzhi Wang is the corresponding author.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apenergy.2024.124069.

References

[1] Lewis Anthony, Estefen Segen, Huckerby John, Lee Kwang Soo, Musial Walter, Pontes Teresa, et al. Ocean energy. In: von Stechow C, Hansen G, Seyboth K, Edenhofer O, Eickemeier P, Matschoss P, Pichs-Madruga R, Schlömer S, Kadner S, Zwickel T, Sokona Y, editors. Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. Cambridge: Cambridge University Press; 2011. p. 497–534.

[2] IRENA. Innovation outlook: Ocean energy technologies. Abu Dhabi: International Renewable Energy Agency; 2020.

[3] Jeffrey Henry, Grattan Kristofer. UK ocean energy review 2022. Retrieved from. https://www.policyandinnovationedinburgh.org/uploads/3/1/4/1/31417803/policy_and_innovation_group_uk_ocean_energy_review_2022.pdf; 2022.

[4] MEC. UK marine energy 2019. Retrieved from. https://www.marineenergywales.co.uk/wp-content/uploads/2019/03/uk_marine_energy_2019.pdf; 2019.
[5] UK government. Net zero strategy: Build back greener. Retrieved from. https://www.gov.uk/government/publications/net-zero-strategy; 2021.
[6] Wind Baltic. All parties in the Danish Parliament agree on a new marine plan. Retrieved from. https://balticwind.eu/all-parties-in-the-danish-parliament-agree-on-a-new-marine-plan/; 2023.
[7] Baker Brannan, Deborah, Heeter, Jenny, & Bird, Lori. (2012). Made with renewable energy: How and why companies are labeling consumer products. Retrieved from https://www.osti.gov/servlets/purl/1037936/.
[8] Niu Baozhuang, Dong Jian, Zeng Fanzhuo. Green manufacturers' power strategy in the smart grid era. Comput Ind Eng 2022;163:107836.
[9] cCarbon. RE100 Initiative: Catalyzing corporate commitment to 100% renewable electricity and demand for voluntary renewable energy certificates (RECs). Retrieved from. https://www.ccarbon.info/article/re100-initiative-catalyzing-corporate-commitment-to-100-renewable-electricity-and-driving-demand-for-voluntary-renewable-energy-certificates-recs-in-the-usa/; 2023.
[10] The Climate Group. We are committed to 100% renewable power. Retrieved from. https://www.there100.org/; 2024.
[11] News Science. Wind makes food retailers greener. Retrieved from. https://www.sciencenews.org/blog/food-for-thought/wind-makes-food-retailers-greener; 2006.
[12] TSINGTAO. 2023 Environmental, Social and Governance Report. Retrieved from. https://www.tsingtao.com.cn/TsingTao/upload/Attachment/20240426/2023%E5%B9%B4%E9%9D%92%E5%B2%9B%E5%95%A4%E9%85%92%E3%80%8A%E7%8E%AF%E5%A2%83%E3%80%81%E7%A4%BE%E4%BC%9A%E5%8F%8A%E7%AE%A1%E6%B2%BB%E6%8A%A5%E5%91%8A%E3%80%8B%E8%8B%B1%E6%96%87.pdf; 2024.
[13] Bahaj AbuBakr S. Generating electricity from the oceans. Renew Sust Energ Rev 2011;15(7):3399–416.
[14] Xiao Dongliang, Lin Zhenjia, Chen Haoyong, Hua Weiqi, Yan Jinyue. Windfall profit-aware stochastic scheduling strategy for industrial virtual power plant with integrated risk-seeking/averse preferences. Appl Energy 2024;357:122460.
[15] Rajabzadeh Hamed, Wiens Marcus. Resilient and sustainable energy supply chains: insights on sourcing and pricing strategies in a non-collaborative and collaborative environment. Int J Prod Res 2024:1–32.
[16] Wang Wenbin, Ferguson Mark E, Hu Shanshan, Souza Gilvan C. Dynamic capacity investment with two competing technologies. Manuf Serv Oper Manag 2013;15(4):616–29.
[17] Yang Peng, Tang Gongguo, Nehorai Arye. A game-theoretic approach for optimal time-of-use electricity pricing. IEEE Trans Power Syst 2013;28(2):884–92.
[18] Dong Ciwei, Ng, Chi To, Cheng TCE. Electricity time-of-use tariff with stochastic demand. Prod Oper Manag 2017;26(1):64–79.
[19] Fattahi Mohammad, Govindan Kannan, Farhadkhani Mehdi. Sustainable supply chain planning for biomass-based power generation with environmental risk and supply uncertainty considerations: a real-life case study. Int J Prod Res 2021;59(10):3084–108.
[20] Xu Xiaofeng, Wang Chenglong, Zhou Peng. GVRP considered oil-gas recovery in refined oil distribution: from an environmental perspective. Int J Prod Econ 2021;235:108078.
[21] Xu Xiaofeng, Lin Ziru, Zhang Wei, Yi Wanli. Multi-tank joint replenishment problem with overlapping time windows in refined oil distribution. Ann Oper Res 2023:1–30.
[22] Xu Xiaofeng, Liu Zhiting, Liu Wenzhi, Pei Chuantao, Wu Xiangfan, Nie Zhengya. A sustainable development benchmarking framework for energy companies based on topic mining and knowledge graph: the case of oil and gas industry. Renew Sust Energ Rev 2024;196:114350.
[23] Zhu Qinghua, Sarkis Joseph, Lai Kee-Hung. Confirmation of a measurement model for green supply chain management practices implementation. Int J Prod Econ 2008;111(2):261–73.
[24] Bai Chunguang, Sarkis Joseph. Green supplier development: analytical evaluation using rough set theory. J Clean Prod 2010;18(12):1200–10.
[25] Zhang Bin, Wang Zhaohua, Lai Kee-hung. Mediating effect of managers' environmental concern: bridge between external pressures and firms' practices of energy conservation in China. J Environ Psychol 2015;43:203–15.
[26] Chen Shaoqing, Chen Bin. Coupling of carbon and energy flows in cities: a meta-analysis and nexus modeling. Appl Energy 2017;194:774–83.
[27] Ding Yi, Shao Changzheng, Yan Jinyue, Song Yonghua, Zhang Chi, Guo Chuangxin. Economical flexibility options for integrating fluctuating wind energy in power systems: the case of China. Appl Energy 2018;228:426–36.
[28] Dong Ciwei, Liu Qingyu, Shen Bin. To be or not to be green? Strategic investment for green product development in a supply chain. Transportation Research Part E: Logistics and Transportation Review 2019;131:193–227.
[29] Shen Bin, Cao Yifan, Xu Xiaoyan. Product line design and quality differentiation for green and non-green products in a supply chain. Int J Prod Res 2020;58(1):148–64.
[30] Chen Shaoqing, Long Huihui, Chen Bin, Feng Kuishuang, Hubacek Klaus. Urban carbon footprints across scale: important considerations for choosing system boundaries. Appl Energy 2020;259:114201.
[31] Chen Shaoqing, Long Huihui, Chen Bin. Assessing urban low-carbon performance from a metabolic perspective. Sci China Earth Sci 2021;64(10):1721–34.
[32] Shen Bin, Zhu Chen, Li Qingying, Wang Xiaofeng. Green technology adoption in textiles and apparel supply chains with environmental taxes. Int J Prod Res 2021;59(14):4157–74.
[33] Zhou Zicheng, Wang Luojia, Shao Shuai Du Kerui. Energy rebound effect in China's manufacturing sector: Fresh evidence from firm-level data. Frontiers of Engineering Management 2022;9(3):439–51.
[34] Hui Hengyu, Bao Minglei, Ding Yi, Yan Jinyue, Song Yonghua. Probabilistic integrated flexible regions of multi-energy industrial parks: conceptualization and characterization. Appl Energy 2023;349:121521.
[35] Zhang Bin, Niu Niu, Li Hao, Wang Zhaohua. Assessing the efforts of coal phaseout for carbon neutrality in China. Appl Energy 2023;352:121924.
[36] Zhang Bin, Xin Qingyao, Chen Siyuan, Yang Zhiying, Wang Zhaohua. Urban spatial structure and commuting-related carbon emissions in China: do monocentric cities emit more? Energy Policy 2024;186:113990.
[37] Aflaki Sam, Netessine Serguei. Strategic investment in renewable energy sources: the effect of supply intermittency. Manuf Serv Oper Manag 2017;19(3):489–507.
[38] Salvador Santiago, Gimeno Luis, Sanz Larruga F, Javier.. The influence of regulatory framework on environmental impact assessment in the development of offshore wind farms in Spain: issues, challenges and solutions. Ocean Coast Manag 2018;161:165–76.
[39] Hoang Anh Tuan, Pham Van Viet, Nguyen Xuan Phuong. Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process. J Clean Prod 2021;305:127161.
[40] Rahman Abidur, Farrok Omar, Mejbaul Haque, Md. Environmental impact of renewable energy source based electrical power plants: solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renew Sustain Energy Rev 2022;161.
[41] Theodora Yiota, Piperis Sotiris. Marine renewable energy perspectives in the Mediterranean region_ planning priorities in a climate neutrality era. Ocean Coast Manag 2022;229.
[42] Jamali Mohammad-Bagher, Rasti-Barzoki Morteza, Khosroshahi Hossein, Altmann Jörn. An evolutionary game-theoretic approach to study the technological transformation of the industrial sector toward renewable electricity procurement: a case study of Iran. Appl Energy 2022;318:119083.
[43] Cui Ying, Zhao Huida. Marine renewable energy project: the environmental implication and sustainable technology. Ocean Coast Manag 2023;232.
[44] Ge Zehui, Hu Qiying, Xia Yusen. Firms' R&D cooperation behavior in a supply chain. Prod Oper Manag 2014;23(4):599–609.
[45] Dong Ciwei, Shen Bin, Chow Pui-Sze, Yang Liu, Ng, Chi To. Sustainability investment under cap-and-trade regulation. Ann Oper Res 2016;240:509–31.
[46] Hu Bin, Mai Yunke, Pekec Sasa. Managing innovation spillover in outsourcing. Prod Oper Manag 2020;29(10):2252–67.
[47] Niu Baozhuang, Chen Yuyang, Zeng Fanzhuo. One step further for procurement cooperation: will the industry leader benefit from its competitive manufacturer's joint determination of consumption quality? Eur J Oper Res 2023;311(3):989–1008.
[48] Niu Baozhuang, Zhang Nan, Xie Fengfeng, Zhang Hailun. Optimisation of carbon emission reduction in a competitive market with varying saturation and eco-conscious consumers. Int J Prod Res 2023:1–24.
[49] Niu Baozhuang, Zhang Nan, Zhang Jianhua. How to induce multinational firms' local sourcing to break carbon lock-in? Eur J Oper Res 2024;315(2):613–25.
[50] Beer CR. 2023 Environmental, social and governance report. Retrieved from. https://www.crbeer.com.hk/sh_zr/hjshjgzbg/202404/P020240424629120285828.pdf; 2024.
[51] Wang Yulan, Niu Baozhuang, Guo Pengfei. On the advantage of quantity leadership when outsourcing production to a competitive contract manufacturer. Prod Oper Manag 2013;22(1):104–19.
[52] Tang Sammi Yu, Kouvelis Panos. Supplier diversification strategies in the presence of yield uncertainty and buyer competition. Manuf Serv Oper Manag 2011;13(4):439–51.
[53] Yano Candace Arai, Lee Hau L. Lot sizing with random yields: a review. Oper Res 1995;43(2):311–34.
[54] Niu Baozhuang, Li Jiawei, Zhang Jie, Cheng Hsing Kenneth, Tan Yinliang. Strategic analysis of dual sourcing and dual channel with an unreliable alternative supplier. Prod Oper Manag 2019;28(3):570–87.
[55] Lus Betul, Muriel Ana. Measuring the impact of increased product substitution on pricing and capacity decisions under linear demand models. Prod Oper Manag 2009;18(1):95–113.
[56] European Commission. Green education initiatives. Retrieved from. https://education.ec.europa.eu/focus-topics/green-education/about-green-education; 2021.
[57] Net Zero Insights. The rising tide of ocean energy. Retrieved from. https://netzeroinsights.com/resources/ocean-energy/; 2023.
[58] Krass Dmitry, Nedorezov Timur, Ovchinnikov Anton. Environmental taxes and the choice of green technology. Prod Oper Manag 2013;22(5):1035–55.
[59] Protocol GHG. Scope 2 frequently asked questions. Retrieved from. https://ghgprotocol.org/scope-2-frequently-asked-questions; 2024.
[60] Consulting ASKCI. Annual data analysis of CR Beer (HK0291). Retrieved from. https://s.askci.com/stock/financialanalysis/HK0291/; 2024.
[61] Consulting ASKCI. Annual data analysis of Tsingtao Brewery (600600). Retrieved from. https://s.askci.com/stock/financialanalysis/600600/; 2024.
[62] PwC. Consumers willing to pay 9.7% sustainability premium, even as cost-of-living and inflationary concerns weigh: PwC 2024 Voice of the consumer survey. *PwC.* Retrieved from. https://www.pwc.com/gx/en/news-room/press-releases/2024/pwc-2024-voice-of-consumer-survey.html; 2024.
[63] Wenling Municipal People's Government. China's first bidirectional tidal power station: 200 million kWh generated in 38 years. Retrieved from. https://www.wl.gov.cn/art/2019/12/10/art_1544471_40977954.html; 2024.
[64] The Climate Reality Project. (2016). 5 Major businesses powered by renewable energy. Retrieved from https://www.climaterealityproject.org/blog/5-major-businesses-powered-renewable-energy.