Scenario Planning for Offshore Wind Supply Chains 2030

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ABSTRACT

The offshore wind industry is expected to be a major contributor to climate change mitigation and renewable energy transition. Supply chain challenges abound in realizing the potential of offshore wind development. This study focuses on devising supply chain strategies especially toward China, to help energy companies fulfil offshore wind development goals. Scaling up offshore wind requires a long-term view; therefore, scenario planning was utilized to help decision makers tackle uncertainties by preparing for several possible futures. Twelve key driving forces were identified. Three scenarios for 2030 and potential supply chain strategies were developed and surveyed in an energy company and an industry business network. Results show different focus areas of sourcing, construction, assembly and installation strategies based on markets and scenarios. The study contributes to decision making for shaping the future of offshore wind supply chain.

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1 Introduction

The world is going through energy transformation, with increasing pressure to decarbonize the energy system by using renewable energy for electricity generation, following the 2015 Paris Agreement to keep global warming well below 2 degrees Celsius above pre-industrial temperature levels. The pressure comes as a result of the continued growth of greenhouse gas emissions, reaching 55.3 GtCO2e in 2018, and the consequent need to cut emissions deeper and faster (UNEP, 2019). As a contributor to climate change mitigation goals and clean energy transition, offshore wind has yet to reach full commercialization. Total global annual offshore wind energy potential is expected to be between 150,000 and 200,000 TWh (terawatt-hour) based on different studies (Arent et al., 2012). Through geospatial analysis and detailed modelling of satellite data, a later study (IEA, 2019a) suggests that the total global technical potential is even higher, with an electricity generation power of above 420,000 TWh per year. This is 11 times the 2040 global demand for electricity. The top three countries with the highest potential, Russia, Australia, Canada, are not the top three countries with the highest installed capacity, UK, Germany, China (Juergens, 2019), indicating untapped potential for many countries (*Figure 1*). Indeed, the global installed capacity is expected to grow from 23GW in 2018 to 342GW in 2040, and even further to 562GW in 2040 with additional policies for sustainable development (IEA, 2019a).

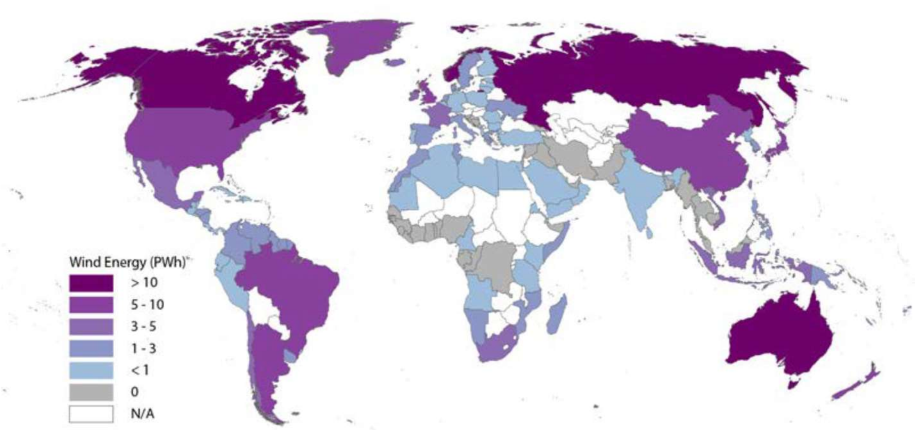


Figure 1: Offshore wind potential by country

In Petawatt-Hour (PWh), all resource and depth classes. (Arent et al., 2012)

The estimate for supply chain contracts in the US offshore wind sector is between 50 and 70 billion US dollars by 2030 (Juergens, 2019; McClellan, 2019). Can this all be fulfilled by local suppliers or does the global supply chain need to be utilized to meet the demand? China has currently 4GW of capacity in operation, being the third largest market after UK and Germany, and is expected to take over as leader in installed capacity (110GW) by 2040 (IEA, 2019a). Will the development of Chinese supplier capability drive the cost down for the sector and change the landscape of offshore wind growth totally? Companies from the traditional oil and gas industry are entering the offshore wind sector to leverage their technical expertise and experience in offshore oil and gas. What will be the implications for them?

No clear answer is found in the literature, and addressing these issues is highly relevant for the sponsor company, for the development of the offshore wind sector, and for getting closer to reaching the climate goals.

1) Scenario planning as a tool

Predicting the future is hard. Related to climate change, thousands of scenarios have been collected in the IPCC (Intergovernmental Panel on Climate Change) mitigation scenario analysis database (Hertwich et al., 2015). Eventual demand for offshore wind depends on relations and interactions between economic systems, climate policy adoption and technological readiness, among others.

Scenario planning is a tool that allows decision makers to shift from predicting to preparing, and to focus strategically on a limited number of key effects instead of an infinite number of events. Even if key uncertainties are uncontrollable, they can interact in a larger system with the better-known trends, and multiple scenarios can be derived after understanding such rules of system interaction (*Figure 2*). In evaluating different strategies across scenarios, decision analysis can be used to structure the process (Goodwin & Wright, 2001).

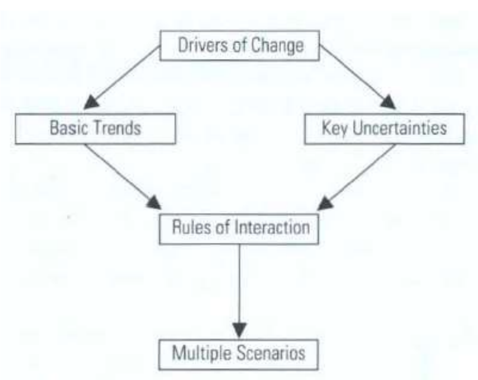


Figure 2: Building blocks for scenarios

(Schoemaker, 1995)

2) Research Question

Decarbonizing the energy system and scaling up the offshore wind sector require a long-term view, which can potentially be realized by structured scenario planning. This research uses scenario planning to devise supply chain strategies toward China to help energy companies fulfill offshore wind development potential and goals. The findings detail strategies across the dimensions of sourcing, construction, assembly and installation in different parts of the world.

2 Literature Review

The focal question of this project – "What should the supply chain strategy be toward China in order to support the planned growth in global offshore wind through 2030?" – will be addressed using scenario planning. This chapter explores scenario planning: its definition, ideal attributes, process, and limitations. It also reviews literature about the specific supply chain challenges for the offshore wind industry.

2.1 Scenario Planning

2.1.1 What Scenario Planning Is and Is Not

Closely related to strategic planning, scenario planning is about telling stories of the future and giving meaning to complex events (Chermack et al., 2001). It is a disciplined methodology for imagining possible futures in which organizational decisions may be played out.

However, scenario planning is not about predicting the future. Rather, it aims to challenge current mental models and direct attention to overlooked elements. Schoemaker (1995, p. 30) suggests that it should "describe generically different futures rather than variations on one theme".

The history of scenario planning can be traced back to the Second World War (Ringland & Schwartz, 1998), when scientists and operations researchers did planning for complex systems to assist military leaders. After the war, similar techniques were applied in corporate planning. Shell has used scenario planning since 1967 and responded successfully to the oil crisis in 1973. It is generally considered a pioneer in effectively using the tool and continued to develop three scenarios in 2005 called "Global 2025 Scenarios" using the "two wins one loss" method. As a result, it has been the first (and, for almost a decade, the only) foreign company to produce and export gas from Russia (Vecchiato, 2019). Today scenario planning is widely used for strategic and long range planning and also as a cognitive aid to judgment biases (Phadnis et al., 2015).

2.1.2 Ideal Attributes

There are certain common criteria for desired scenario sets and scenarios (Caplice & Phadnis, 2013). Ideal sets typically have no more than four scenarios, contain alternatives, and are challenging and at the same time differentiated. Ideal scenarios are focused on the fundamental issue, plausible, internally consistent, memorable and don't answer the focal question directly.

2.1.3 Process and Approaches

In *The Art of the Long View*, Schwartz (2012) details the process and methods of scenario planning. The methodology of scenario planning typically calls for eight steps. Step one is to identify the focal issue, from the inside out toward the environment. Step two is to find key local factors related to the stakeholders of the organization. This step evaluates what is determined to be success or failure of the focal issue. Step three is to find driving forces in the macro-environment that influence the key local factors yet are beyond the control of the organization. This step requires the most research in the process and the key challenge is to anticipate novelty or trend breaks. Step four is to rank and determine the most important and uncertain driving forces. Step five is to select scenario logics, which entails identifying a few different scenarios and presenting them along a spectrum, matrix or volume. The distinct scenarios must tell differences, and typically include contrasting two most important with two most uncertain driving forces. Step six is to create a narrative of the skeletal scenarios. Step seven is to uncover implications for the focal issue identified in step one. Step eight is to identify the leading indicators and signposts to be monitored. This last step provides helpful insights into how the future may affect strategic decisions of the industry.

The process identified by Schoemaker (1995) is very similar, but has two more steps to stress the iterative nature of the process to incorporate research and quantitative models and the need to test for internal consistency.

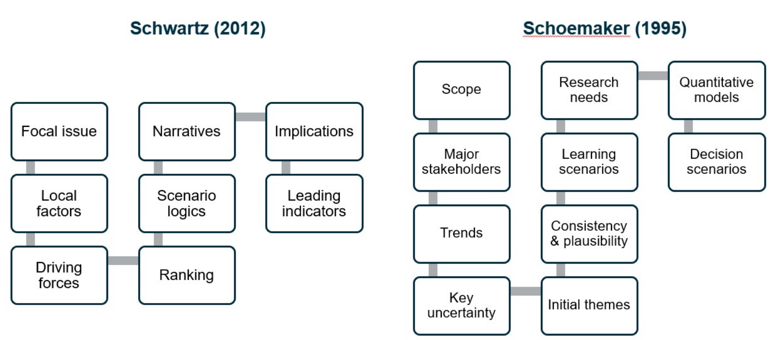


Figure 3: Steps of scenario planning

Schwartz (2012) vs. Schoemaker (1995)

Once scenarios are developed, a hierarchical decision analysis can be used to evaluate alternative strategies across scenarios (Goodwin & Wright, 2001). System dynamics approach, which was first developed in 1961 by Jay Forrester to look at supply-demand interconnection, can also be used for scenario planning, as seen in a paper to model tourism development scenarios (Mai & Smith, 2018). Participatory approach (Flynn et al., 2018) is often used for scenario planning even though extensive community engagement is a challenge. The stages most commonly completed with participation are context, scenario review/feedback and option identification, which are where this study also aims to complete with participation.

2.1.4 Limitation and Criticism

Two limitations of scenario planning have been identified in literature (Chermack et al., 2001). One is that the methodology lacks a theoretical foundation. The other is that it is often hard to measure the results and impact of participation. As such, the usefulness of scenario planning is sometimes questioned as "anecdotal", and it is often hard to judge the decision outcomes as a result of scenario planning. This study will consider these limitations while developing the scenarios.

2.2 Challenges of Supply Chain in Offshore Wind

A study in Europe and China shows challenges in supply chain for deployment of offshore wind (Poulsen & Lema, 2017). It concluded that a global supply chain specifically in terms of logistics is not ready for the renewable transformation. Barriers, bottlenecks and constraints abound in supply chain. While the separate chains tend to function as silos, a supply chain needs to be highly coordinated among up- and downstream linkages which can span many industries. Bottlenecks can be related to vessel availability and port infrastructure, while constraints are salient in shipping and logistics. Poulsen and Lema (2017) call for political binding for offshore wind beyond 2020 in Europe, while having the Chinese players acquire more know-how from Europe to accelerate diffusion of the technology. This may serve as a lesson learned for the development of offshore wind in the U.S.

Moreover, supply chain is indicated as a main driver for cost reduction of LCOE for offshore wind, especially in the area of installation, operation maintenance and logistics (Maples et al., 2013; Poulsen & Hasager, 2016).

Using a hybrid life cycle assessment (LCA) method to assess life cycle inventories of offshore wind farms can indicate the levels of material requirements from construction to energy production. It is shown that wind power plants are more material intensive per unit of generation than fossil-fuel based electricity generation (Hertwich et al., 2015). In climate change mitigation scenarios, the initial requirements to install new capacity would require high demand for iron and cement. Rare earth materials such as neodymium required for offshore wind turbines can also limit scaling ambitions and targets and thus provide a bottleneck for supply chain (Fishman & Graedel, 2019; Skopljak, 2019).

Assessment of the environmental impacts of LCA reveals the importance of installation, operation and maintenance, which influences the overall costs of supply chain (Arvesen et al., 2013). A study of a typical offshore wind farm in China using a process-based life-cycle inventory model also reveals the life-cycle environmental footprints of wind energy production at 25.5g CO_2-eq/kWh mainly by wind turbine and foundation material manufacture (Yang et al., 2018). Therefore, while designing supply chain for offshore wind farms, projects shall carefully evaluate the financial as well as environmental costs of material requirements, installation, operation and maintenance, in order to maximize the sustainability efforts of energy transition to mitigate climate change.

2.3 Summary

This section provides an overview of the literature related to scenario planning as a tool to help answer the focal question. Scenario planning is an effective tool for long range planning. While it is forward looking, the focus is equally on what one can do today to react or respond to a future scenario.

The industry of offshore wind is in its early phase of development and has great growth potential. The uncertainty that lies in the future trajectory of the industry and its supply chain as shown in the review of key challenges call for long term planning. The process of scenario planning can derive several plausible scenarios under which the relevant offshore wind companies can develop key strategic insights.

3 Methodology

This chapter explains in detail the scenario planning approach and applies it to the research problem of offshore wind supply chain strategy. The approach chosen is the one developed by Schwartz (2012). It starts by identifying the focal issue, then determines the relevant internal factors and external driving forces. The next steps rank the driving forces to develop the scenario logics, and eventually three scenario narratives. The last steps involve deriving implications and developing leading indicators for monitoring the future scenarios.

3.1 Focal Issue

The key question is how to design supply chain strategy toward China for an upstream energy company with a set goal of revenue growth in the offshore wind industry by 2030. The supply chain scope of work for such a company typically includes sourcing, construction, installation, and may eventually include maintenance and decommissioning of offshore wind farms. As shown in *Figure 4*, the scope belongs to all three categories of expenditure, capital, operational, and decommissioning. The focus of this study is on the CAPEX and OPEX related activities, because the industry is still in its development phase.

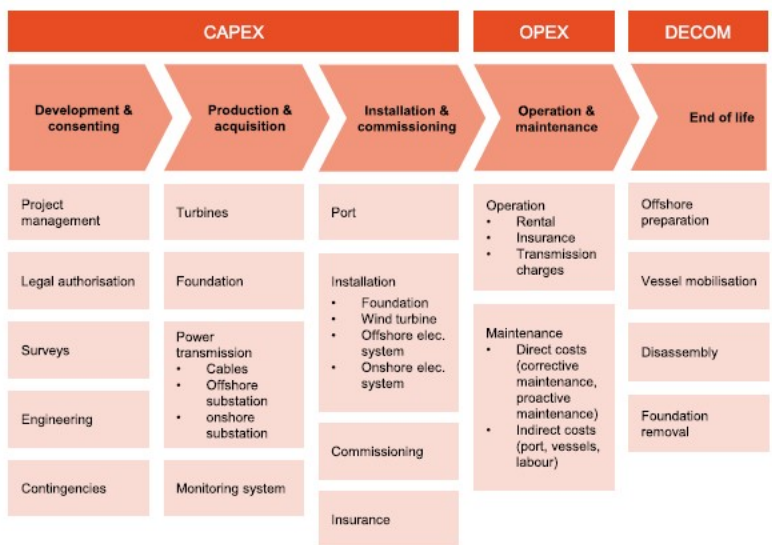


Figure 4: Breakdown of lifecycle cost of a wind farm

(Bosch et al., 2019)

3.2 Local Factors

In the second step, local factors which will affect the success of the focal question are explored. Whether a supply chain strategy is determined to be a success or not largely depends on how effectively it helps firm-wide revenue generation. This requires that supply chain strategy supports project acquisition and a healthy pipeline, fulfilling engineering and client requirements.

In order to realize a wind farm project, the supply chain function performs procurement of turbines, foundation, power transmission, control systems, and other key manufactured components from various suppliers. It also is responsible for deciding logistic solutions during system integration, construction, assembly and installation. During the lifetime of system operation, it may be responsible for maintenance work related to suppliers and logistics.

In measuring effectiveness, the supply chain strategy should contribute to minimum cost, on time project delivery schedule with high quality standard, which are the local factors at company level.

3.3 Driving Forces

Many forces in the macro-environment drive the local factors for an industry player in offshore wind. However, these trends are not controlled by single organizations. The following sections detail the snapshots of trends and uncertainties as driving forces.

1) International climate goals

After the 2015 Paris Agreement, the international communities continued to reconvene at UN Climate Change Conferences to set emissions goals and mitigation targets. The 2020 conference will be held in November in Glasgow, Scotland, UK. The concerted efforts can either be strengthened or weakened, and as a result, regional and national climate change goals and renewable energy targets will vary. As an example, the US gave a formal notice of intention to withdraw from the Paris Agreement in 2019 (Friedman, 2019), which would be effective in November 2020. This creates a negative impact on global climate change mitigation efforts and in turn affects demand for offshore wind.

2) Government policies on renewable energy deployment

There already are country and regional level specific policies targeting at least 10 GW installed capacity of offshore wind within 2030, such as the EU, China and the US (IEA, 2019b). However, stated policy may not be achieved, can be revised or even reversed, and this will affect the industry accordingly.

3) China's renewable energy and offshore wind policy

China set in 2009 an offshore wind price ranging from 0.62 to 0.97 RMB/kwh and a policy to simplify the price mechanism for wind power including offshore wind (Yuan et al., 2014). However, there has been a disordered and unbalanced pattern of wind farm development as well as lack of market response. It is uncertain whether China will regulate offshore wind and renewable energy further or allow more market freedom where international players can compete locally. The uncertainty affects demand for offshore wind from China and development of local supply chains.

4) Local content requirements

Almost every country has local content requirements for building its offshore wind farms. The US has state-level regulatory bodies as well, such as the California Energy Commission, in addition to the national Bureau of Ocean Energy Management (BOEM) (Collier, 2017). A high percentage of local content can be a result of more rapid market growth and can further incentivize increased level of supply chain and local manufacturer activities. However, projects cannot get started with stringent local content requirements.

Whether these requirements can be loosened at an initial stage in order to boost development will affect how fast the industry will grow. This uncertainty affects decisions to source internationally or locally.

5) Material costs and availability

a. Steel

Fabricated steel is expected to account for a large portion of the floating platform hull cost. In addition, secondary steel items include structures for personnel access and conduits for array cables (IRENA, 2016). Developers are seeking to improve design standards and design capability of foundations in order to reduce steel mass (IRENA, 2016). In the meantime, steel's high value coupled with volatility of its price, which more than doubled from 2016 to 2019, makes it a commodity of high purchasing importance and low complexity of supply market (Kraljic, 1983), as shown in *Figure 5*.

b. Neodymium

The rare-earth material neodymium is needed for offshore wind generator's permanent magnets, and the production is dominated by China (Fishman & Graedel, 2019). A total of 15.5 Gg (15.5 kt) of neodymium may be required by 2050 in the US, even if 20% can be saved through recycling technologies. The trade relationships between China and the US may cause potential bottlenecks for sourcing this material in the US and even pose risks for global supply chain to meet the expected growth of offshore wind farm construction. Based on the criticality and scarcity of this material for wind production, it is deemed to be of high purchasing importance and high complexity of supply market (Kraljic, 1983), as shown in *Figure 5*.

c. Fuel and logistics

Logistics costs during construction can account for between 0.6% and 7.6% of LCOE (Chartron, 2019). However, as the wind turbine size gets larger, offshore logistics costs will have less impact on the LCOE. In order to further reduce LCOE impact, several areas can be worked on based on the study of Chartron (2019). Weather limits can be loosened to decrease waiting on weather-related costs and work offshore shall be minimally deployed. In addition, opportunities exist in process improvement, economies of scale and vessel utilization optimization. The volatility of fuel price makes the logistics costs of high importance of purchasing and low complexity of supply market (Kraljic, 1983), as shown in *Figure 5*.

d. Turbine

Turbines account for 30-40% of total costs and are getting bigger in both size and capacity (standard is 8-10 megawatts) (IEA, 2019b) and requiring more complex supply chains. The market currently has few turbine suppliers with low competition level and high barriers to entry. The major turbine manufacturers have production in-house and exclusive agreements with suppliers (D'Amico et al., 2017). However, to meet increasing global demand, new participants are needed. The emerging Chinese suppliers account for five of the top 10 leading turbine manufacturers in the world in 2018 (IEA, 2019b). Further offshore wind development requires more distributed models, less vertical integration, and collaborative risk-sharing contracts for turbine manufacturers. Turbines are therefore considered of high importance in purchasing and high complexity in supply market (Kraljic, 1983), as shown in *Figure 5*, due to their high-value components, technological complexity and long-term strategic impact.

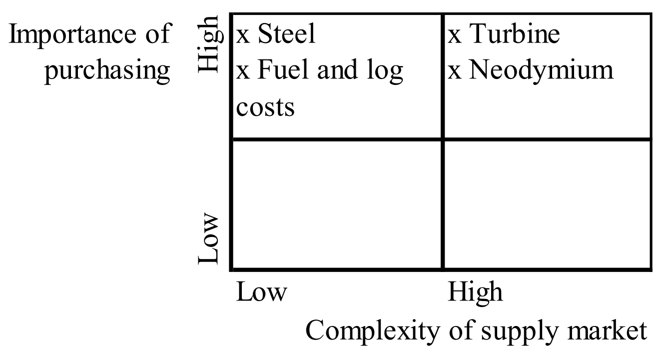


Figure 5: Purchasing sophistication matrix of key material

6) Advancement of floating platform technologies

As promising as the floating offshore wind system can be by reducing long-term LCOE by 60%, it also poses main technical challenges of mooring and anchoring concepts in shallow and deep waters alike (W. Musial et al., 2018). The advancement of floating platform technologies may see either competition or domination of a few key technological players. This will affect where projects will source from, based on technological readiness. The uncertainty affects capability development of suppliers and competition among them.

7) Port infrastructure availability and capacity

The availability and capacity of port infrastructure put a constraint on construction and assembly. As turbine size and project size both grow, existing ports need to be upgraded; otherwise they will be strained by heavy lifting, ship access, and laydown space (W. D. Musial et al., 2019). As an example, due to lack of port infrastructure, the first and only offshore wind farm in the US, the Block Island Wind Farm off the coast of

Rhode Island, which went operative in May 2017 (Garfield, 2017), did not have any local assembly at port. Cargo ships with assembled components docked in Providence, RI before going to final site, and a jack-up vessel performed turbine installation directly on site offshore (Egan, 2016).

8) US – China and global trade relations

Trade relations affect the risk of sourcing from China. Any straining of trade relations, such as what happened in 2019 between the US and China, would create a challenge in sourcing critical materials such as neodymium from China (Snieckus, 2019). Such a trade dispute can give rise to a global trade war, and imposition of tariffs would cause increase of turbine price to as high as 10% (Hook, 2019). At the same time, it would limit Chinese turbine manufacturers' opportunities in the US to be part of a competitive solution in wind farm construction.

9) Growth of US offshore wind industry

The cumulative installed capacity of offshore wind in the US as of 2018 (30 MW) is negligible compared to other countries, accounting for around approximately 0.1% of the world's total 22,592MW (W. D. Musial et al., 2019). Yet the US is among the top 10 countries in terms of technical potential, with a share of almost 10% of global potential (Arent et al., 2012). Faster growth of the US market would increase demand from the US and accelerate local supply chain building, whereas continuously stagnant growth would slow the pace of offshore wind development as well as renewable energy transition globally.

10) Regulation of transmission assets ownership

With increased distances from shore, offshore wind farms require new transmission connection technologies, switching from HVAC (High-Voltage Alternating Current) to HVDC (High-Voltage Direct Current), and regulation models to drive down project costs (IEA, 2019a). However, it is not certain who should bear the cost and own transmission assets. Countries differ in their regulation about whether it should be transmission system operator, government or project developer that owns such assets. Such regulation directly affects the scope of supply chain work about whether to include cable and substation or not.

11) Exclusive agreements with second-tier suppliers

Leading turbine manufacturers can impose exclusive agreements with their upstream suppliers to allow more power to be leveraged (D'Amico et al., 2017). They strive to protect intellectual property as well as internal investments in research and development. Such behavior does not promote competition and can jeopardize economies of scale and the learning curve of the industry.

12) Availability of Jones Act compliant vessels in the US

The Jones Act from 1920 requires goods-transporting ships in US ports to be built, owned, operated by US citizens or permanent residents. The unavailability of such vessels in the US as of 2019 provides a constraint on the logistics and installation of turbine components (W. D. Musial et al., 2019). The example of the Block Island Wind Farm reveals the lack of Jones Act-compliant heavy-lift jack-up vessels which are required to install wind turbines. As a result, a Norwegian ship was deployed for installation.

3.4 Ranking of Driving Forces

The 12 driving forces listed above are assessed across 9 dimensions. The first five dimensions are general classification of social, technological, economic, environmental, and political. The other four dimensions are impact of cost reduction (low or high-level mechanism) and geography (international and local).

Ranking of the driving forces is then done based on two criteria. One is how important the factor is to the focal issue of offshore wind supply chain strategy toward China; the other is how uncertain the factor is. *Figure 6* lists all the driving forces across all the dimensions, along with rankings in terms of importance and uncertainty.

No.	Driving Force	Social	Technological	Economic	Environmental	Political	High-level	Low-level	International	Local	Comments	Importance	Uncertainty
1	International climate goals	x			x	x	x		x		Uncertainty of total demand for offshore wind	8	2
2	Governmental policies for renewable energy				x	x	x			x	Uncertainty of local demand for offshore wind	9	1
3	Regulation of China's offshore wind industry					x	x			x	Uncertainty of demand for offshore wind from China	1	3
4	Local content requirements					x		x		x	Whether to source internationally or locally	3	4
5	Material cost and availability			x				x			What sourcing strategy to use at material level	10	8
a	Steel			x				x					
b	Neodymium			x				x					
c	Fuel and logistics			x				x					
d	Turbine (including neodymium)		x					x					
6	Advancement of floating platform technologies		x					x			Capability development and competition of suppliers	5	10
7	Port infrastructure availability and capacity			x				x			Construction and assembly constraints	6	7
8	US-China and global trade relations	x		x		x	x		x		Whether to source from China	2	5
9	Growth of US offshore wind industry				x	x	x			x	Uncertainty of demand for offshore wind from the US	4	6
10	Regulation of transmission assets ownership					x		x		x	Scope of cable and substation	12	11
11	Exclusive agreements with 2nd tier suppliers			x		x				x	Power of turbine suppliers	11	12
12	Availability of Jones Act compliant vessels in the US		x	x			x			x	Logistics and installation constraints	7	9

Figure 6: Classification of the 12 driving forces

3.5 Scenario Logics

The research team made the assessments shown in *Figure 6* for the purpose of designing scenarios. In assessing all the driving forces, three were deemed to be the most critical and uncertain: 3) regulation of China's offshore wind industry, 4) local content requirements and 8) US-China and global trade relations, in order to derive scenarios. Accordingly, two dichotomies exist: whether or not China allows its offshore wind (OSW) market to be open to the outside world, and whether or not the outside world has stringent local content requirements (therefore allowing Chinese supply or not). Of the four possible outcomes, the one where China is open to international suppliers while Chinese suppliers cannot supply to the rest of the world is not very plausible for offshore wind, since China probably would not prohibit its suppliers from going abroad while opening its domestic market to the world. Therefore, three scenarios are developed as illustrated in *Figure 7*.

		World OSW market open to China	
		Yes	No
China OSW market open to the world	Yes	A Free and Green World	-
	No	A Made-in-China World	A Closed World

Figure 7: Three scenarios and combination of most important driving forces

3.6 Scenario Narratives for 2030

In developing the scenario narratives, all the driving forces are examined and fit to each scenario. The evaluation of their impact under each scenario is summarized in *Figure 8*.

		A free and green world	A closed world	A made-in-China world
1	International climate goals	+	-	+
2	Increased governmental policies for renewable energy	+	-	+
3	Regulation of China's offshore wind industry	-	+	+
4	Local content requirements	-	+	+
5	Material cost and availability			
	Steel			
	Neodymium	+	-	+
	Fuel and logistics			
	Turbine (including neodymium)			
6	Advancement of floating platform technologies	+	-	+
7	Port infrastructure availability and capacity - US	+	-	+
8	US-China and global trade relations	+	-	+-
9	Growth of US offshore wind industry	+	-	+
10	Regulation of transmission assets ownership	+	-	+
11	Exclusive agreements with 2nd tier suppliers	-	+	+-
12	Availability of Jones Act compliant vessels in the US	+	-	+

Figure 8: Driving forces and scenarios

The scenario narratives were part of a survey done by the author using Qualtrics. The survey was used as a virtual scenario planning session where the respondents were prompted with the scenarios and asked to respond to them by selecting the optimal supply chain strategies for different markets. Respondents could also leave comments or suggestions under each scenario. The survey was first tested for a trial run with students and received 18 responses. Then it was distributed at the sponsoring company within the offshore wind and supply chain business units and an industry network in March and April 2020. 16 and 8 responses were collected respectively. Respondents' years of experience in the energy sector ranged from 2 to 40. The full survey is attached in the Appendix. The basis for all three 2030 scenarios is World Energy Outlook 2019 (IEA, 2019b).

3.6.1 A Free and Green World (Open China)

China is open to a Free and Green World in 2030. The global community is committed to combatting climate change through favorable policies for renewable energy development. National and regional governments not only fulfilled their stated policies as of mid-2019, targeting at least 10 GW of offshore wind construction capacity by 2030, but also went above and beyond to adopt more stringent energy policies for lower emissions, realizing the sustainable development scenario set by the International Energy Agency

(IEA). The world's total energy demand decreased as a result of declining oil and coal use, while renewable energy demand rose steadily.

Demand for offshore wind rose significantly across the globe, realizing its trillion-dollar investment potential into 2040 as claimed by IEA, allowing for a healthy project pipeline. Free trade means that suppliers enhance their capabilities to compete not only in local markets but also globally. Local content requirements are largely loosened. China increases its internal demand for offshore wind and allows sourcing from international suppliers. At the same time, Chinese turbine suppliers continue to improve their technology and assume more dominant positions in the global market. Yet Chinese component suppliers alone cannot fulfill the increasing global demand. Advancement of floating platform technologies opens new doors for more suppliers to enter the market. Especially in the US market, as port infrastructures are added, they expand capacity for and availability of local logistics operations. US suppliers emerge to build and operate Jones Act compliant vessels. (The Act from 1920 requires US port goods-transporting ships to be built, owned, and operated by US citizens or permanent residents.) The EU continues to be an ideal location for both large offshore wind projects as well as mature component suppliers, supported by regional political efforts and collaboration especially driving operational excellence in transmission assets ownership.

3.6.2 A Closed World (Closed China)

China is closed to the outside world, supplying and fulfilling only internal demand for offshore wind in 2030. Global trade wars hurt economies in developed countries. President Donald Trump won a second term, and the US left the Paris Agreement as planned resolutely on November 4, 2020, one day after the 2020 US Presidential election. Other countries followed suit. The commitment to offshore wind development declined as countries lost budgets for renewable energy projects. Not even the already stated policies (according to IEA's Stated Energy Policies Scenario) for climate change mitigation were realized and the momentum for clean energy technologies slowed down.

For existing offshore wind development projects in the pipeline in the EU and the US, neodymium (made into NdFeB permanent magnets) as a key component for wind turbine generators becomes increasingly difficult to source from China for the US and US allied countries. China remains, same as 2020, the single source country where most of this rare-earth metal is mined. The closure of China forces the US to reopen its Mountain Pass (CA) rare earth mine which was closed as of 2019.

It is hard and almost impossible to deal with and source from Chinese suppliers as they become fully occupied with fulfilling local content requirements and the increasing local market demand. Local content requirements remain high in the rest of the world. Some UK projects reached 86% of local content in operations and maintenance as of 2019 (Juergens, 2019), and after Brexit in 2020 the local content obligation for all pipeline projects became even higher. Across the world the rise of populism continues, and less international trade results in stagnant economic growth worldwide.

3.6.3 A Made-in-China World (What China Makes, the World Takes)

China remains on target with its stated policy as well as sustainable development ambitions for offshore wind development. In 2030 it is on track with its plan to increase offshore wind installation capacity to 175 GW by 2040, and to utilize offshore wind to contribute to 5% of total electricity generation by 2040. However, the growth benefits only the local economy as stringent local content requirements make it extremely difficult for foreign competitors to set foot in project execution unless they have joint ventures with local companies. Such growth fuels the development of capabilities and technologies of Chinese supply chain, which is either vertically integrated into the developer-owner-operator companies or independent.

The booming local market also drives the learning curve, economies of scale and cost reduction for the Chinese component suppliers. This is especially true for the turbine manufacturers, which become even more competitive. As of 2019, already five of the top 10 offshore wind turbine manufacturers were in China. Following ambitious global expansion through low cost and satisfactory quality, they occupy eight spots on the top 10 list by the end of 2030; plus, they replace the dominant positions of Siemens Gamesa and MHI Vestas. Thanks to China's growth the cost of the offshore wind technology reduces significantly across the world, making it a more viable and sustainable choice for electricity generation in the US and EU and the rest of the world vis-à-vis other renewable technologies. Thus, the industry grows internationally and in the long run local supply chains are developed in the main world regions of China, Europe and the US.

3.7 Implications

Each scenario may call for a different set of supply chain strategies. Such strategies are further broken into sourcing, construction, and assembly / installation. Each stage may pose its unique challenges. For sourcing strategy, decisions are to be made along a continuum (from 0 to 5) from hands-off / delegate at one extreme to invest / partner at the other (*Figure 9*). Hands-off / delegate involves delegating responsibility to suppliers, keeping few first-tier suppliers. Invest / Partner involves developing strategic and close partnership with suppliers, engaging with many first-tier suppliers.

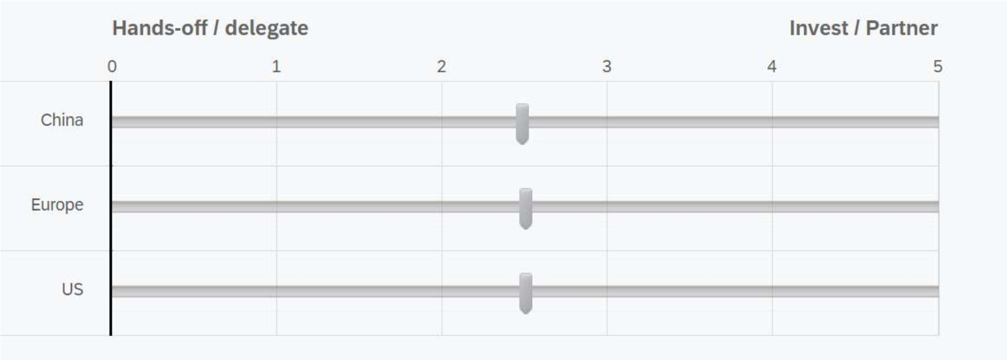


Figure 9: Sourcing strategy

Along the construction strategy continuum lies sub-contract and vertically integrate (*Figure 10*). Sub-contract encompasses engaging as many external partners and suppliers as possible to do construction. Vertically integrate encompasses constructing as much as possible in-house in local manufacturing facilities.

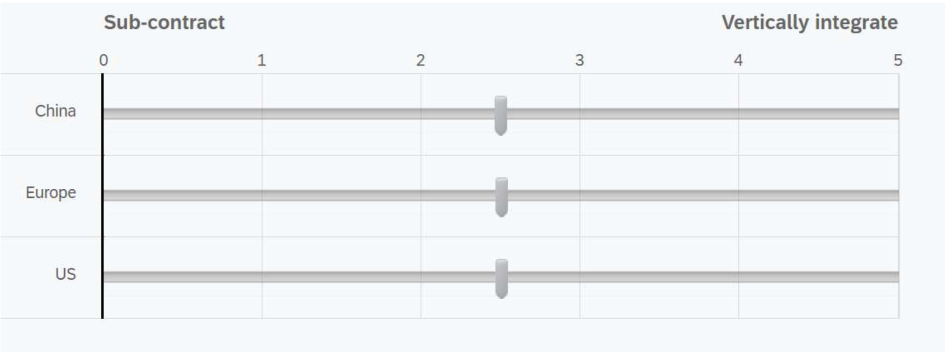
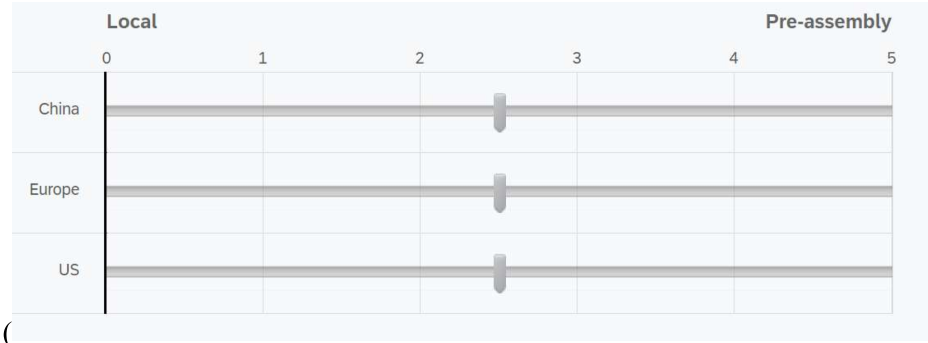


Figure 10: Construction strategy

The continuum from local to pre-assembly denotes the assembly / installation strategy



(

Figure 11). Local means assembling and installing components as much as possible in local ports or offshore on the farm. Pre-assembly means pre-assembling and installing components as much as possible before shipping to local ports.

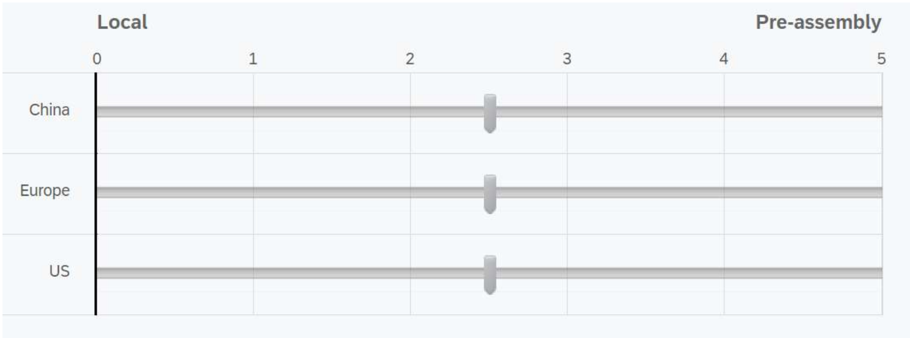


Figure 11: Assembly / Installation strategy

Under each scenario, respondents were presented with these three decision points for all the three specific supply chain strategy categories, across three geographies of China, Europe and the US, representing the biggest markets or markets-to-be for offshore wind. In the scenario of a Closed World, it would not be possible to enter the Chinese market; therefore, the decision points are reduced by three. The total number of decision points is therefore 24.

3.8 Leading Indicators

Some indicators are identified to anticipate which scenario will unfold. For the three scenarios developed for offshore wind, the leading indicators can include number of trade disputes recorded in WTO, number of countries that move away from Paris Agreement, changes tracked in Chinese renewable energy policy, and percentage of local content required in the biggest offshore wind markets.

4 Results and Analysis

4.1 Results

The survey responses from 16 participants at the sponsoring company are summarized in *Figure 12*. Comparison can be made vertically for each supply chain decision and each market.

For sourcing strategy in China, the respondents indicated that in either of the two scenarios of a Free and Green World and a Made-in-China World, the company should partner with and even invest in key suppliers there to cultivate long-term relationship. For construction strategy in China, action is contingent on the scenario. If a Made-in-China World plays out, then it is viable to try to vertically integrate through acquiring or building local manufacturing facilities. In a Free and Green World, there is less urge to do that. When it comes to assembly and installation strategy in China, there is no clear advantage of either local assembly or pre-assembly in the case of a Free and Green World. In case it turns out to be a Made-in-China World, it will make more sense to assemble everything locally.

For sourcing strategy in Europe, a Free and Green World calls for more partnership with suppliers. For construction strategy in Europe, only a Closed World scenario calls for vertical integration. For assembly and installation strategy in Europe, pre-assembly offshore is most relevant in a Free and Green World.

Sourcing strategy for projects in the US leans toward partnership with suppliers when it is a Free and Green World. Construction strategy in the US sees no clear advantage of sub-contract or vertically integrating across the three scenarios, leaning a bit toward vertically integrating when it is a Closed or Made-in-China World. Assembly and installation in the US favor pre-assembly in the Free and Green World scenario.

In addition, survey participants provided comments on the questions "As general policy is considered here, would you treat any critical component differently? Any additional comments or insights about what you would do in this scenario?"

Critical Components	**Additional Comments**
· Floating structures (would be treated differently)	· Use individuals with experience in projects regardless of nationality. Try to use as much local suppliers while maintaining quality.
· Wind Turbine Generators would typically come out of the global supply chain as fully assembled as practical, same with cables, while foundations make sense to look to do as much as possible locally	· The size of the potential offshore wind market will dwarf what we have seen in the traditional offshore energy sector ever. It may surpass the global capacity of vendors for turbines, electrical cables, mooring systems and other critical components. Fabrication, integration and installation of the offshore wind units will also require large storage areas both on land and in quayside which will limit the number of contractors and locations for such activities.
· Critical components, hull and turbines should be treated separately. Remaining is more or less commodities	· Keep the shipment of components as short as possible to hold down the CO_2 and meet the local governments' local content requirements
· Keep control of hull fabrication / assembly and turbines deliveries. Remaining equipment are commodities (more or less off the shelf)	· Be very focused on risk / opportunity management

· Foundations, in particular for floating would need to be considered due to logistical impacts of shipping.	· Make sure you secure the capacity with the key vendors.

The responses from eight participants of the industry network are summarized in *Figure 13*. Comparison can be made vertically for each supply chain decision and each market.

For sourcing strategy in China, more emphasis is given to partnership with key suppliers in a Free and Green World scenario. For construction strategy in China, action is contingent on the scenario. If a Made-in-China World plays out, as opposed to the responses from the sponsoring company, the consensus by this group is leaning toward sub-contracting. In a Free and Green World, more focus is given to vertical integration. When it comes to assembly and installation strategy in China, there is no clear advantage of either local assembly or pre-assembly in case of a Free and Green World. In case it turns out to be a Made-in-China World, it will make more sense to assemble everything locally.

For sourcing strategy in Europe, both the Free and Green World and Closed World scenarios call for more partnership with suppliers. For construction strategy in Europe, only a Closed World scenario calls for vertical integration, consistent with the results from the sponsoring company. For assembly and installation strategy in Europe, local assembly is always preferred and slightly favored in a Free and Green World.

Sourcing strategy for projects in the US leans toward partnership with suppliers when it is a Closed World. Construction strategy in the US sees more advantage to vertically integrate in a Closed World. Assembly and installation in the US favor local assembly in all three scenarios.

In addition, the industry network participants provided comments on the questions "As general policy is considered here, would you treat any critical component differently? Any additional comments or insights about what you would do in this scenario?"

Additional Comments
· Pre-assembly and shipment of critical components is included in the numbers listed above.
· Construction and Project Management would be the most optimal position for our company. Critical components would need pre-assembly.

The leading indicators regarding which scenario is most likely to happen in 2030 will inform the decision of which supply chain strategies to follow.

Figure 12: Survey results from the energy company

(Red line denotes the highest value for a region/country across the scenarios for a strategy.)

Figure 13: Survey results from the industry network

(Red line denotes the highest value for a region/country across the scenarios for a strategy.)

4.2 Limitations

This scenario planning exercise was based on certain assumptions. It assumes offshore wind growth, but because of the COVID-19 pandemic some slow-down is expected. It assumes that Europe will have steady growth; however, many countries there have suffered from the lockdown which will impact all industries, renewable included. Although the exercise did not consider the outbreak due to timing, the world and renewable energy landscape will look different post-Coronavirus. This study also assumes that China will be a willing exporter of offshore wind technology.

5 Discussion

5.1 Sourcing Strategy

Figure 14: Comparison of sourcing strategy responses

(Red line denotes the highest value for a region/country across the scenarios for a strategy.)

For the Chinese market's sourcing strategy, in the scenario of a Free and Green World, the respondents of both groups lean toward investing in suppliers and developing supplier relationships. However, the responses diverge for the scenario of a Made-in-China World, with the industry group leaning more toward hands-off and delegation to the suppliers. An interpretation of this response is that if the offshore wind industry relies a lot on Chinese suppliers in 2030, then they will have developed a lot of capability and sourcing from them for projects in China will require less control. As a result, the supplier network can be left with more delegation, reducing companies' interface risk. However, I would align with the energy company's responses and argue that the optimal sourcing strategy is to partner closely with key Chinese suppliers for projects in China in a Made-in-China World, to the extent of direct joint-venture investment, for two reasons. First, the domination of these suppliers in the whole industry everywhere in the world can potentially bring financial returns. Second, the scenario stipulates that it would be a challenge to operate in the local Chinese market without local partnerships.

In the European market, in both scenarios of a Free and Green World and a Closed World, the sourcing strategy called for is partnership with suppliers, even slightly higher toward this strategy in a Free and Green World by the sponsoring company respondents. To me, however, such a strategy should be utilized more in a Closed World scenario. This is because industry growth would be stagnant and local content requirements would be high, coupled with a lack of Chinese suppliers, causing companies and local suppliers to depend more on each other through closer collaboration to realize projects. In a Free and Green World, companies can expect less need to invest in established suppliers and may only need to partner with new potential Chinese suppliers if any. In the scenario of a Made-in-China World, there is more tendency to use the delegation strategy, most likely attributed to a mature European and Chinese supplier base requiring no extra efforts.

Like Europe, the two group responses coincide in having a partnership strategy with suppliers in both scenarios of a Free and Green World and a Closed World in the US. I strongly agree here and more so in the Free and Green World scenario. US does not have any local supplier as of 2019, so with steady market growth envisioned in the Free and Green World, it is paramount to build local supply chain by cultivating strategic supplier relationships, some of which can potentially come from the oil and gas industry. In a Made-in-China World, the responses are in the middle, slightly leaning toward strategic partnership. However, I would argue that since in this scenario growth will be rapid in the US and electricity cost will be pushed low, companies can adopt the same hands-off sourcing strategy as in the European market.

5.2 Construction Strategy

Figure 15: Comparison of construction strategy responses

(Red line denotes the highest value for a region/country across the scenarios for a strategy.)

For the Chinese market, the two group respondents both give more preference for vertical integration in construction in a Free and Green World, whereas vertical integration is favored only by the sponsoring company respondents in a Made-in-China World. I would lean toward this construction strategy in both of these scenarios and even more in the Made-in-China World, because supplier base will be even more concentrated in China in that scenario and it would almost be mandatory to move manufacturing site locally to China close to this base, given that otherwise the market would not be open to foreign players. In a Free and Green World, construction can be done at first in other Asian sites if possible and then in the long term it can be moved to China.

For Europe, the group consensus is to have vertical integration in the Closed World scenario, due to the local content requirements. For the other two scenarios, a Free and Green World and a Made-in-China World where growth is assumed, the tendency is to sub-contract as many external parties as possible to do construction. This is most likely due to expected high volume of projects in the pipeline, driving companies to outsource more operations to fulfill orders and drive costs down, more so in a Made-in-China World where cost competitiveness is critical to success.

For the US, construction strategy depends on the scenario. A Closed World scenario calls for vertical integration the most where companies must utilize existing sites in the US or in the region to do construction. A Free and Green World calls for vertical integration where possible and implies developing new construction sites locally. In a Made-in-China World, even though both groups responded in the middle slightly leaning towards vertical integration, I would argue for sub-contracting, for the same reason as in the European market.

5.3 Assembly and Installation Strategy

Figure 16: Comparison of assembly / installation strategy responses

(Red line denotes the highest value for a region/country across the scenarios for a strategy.)

For China, there was consensus among the two groups about assembly and installation strategy. In a Free and Green World, the indication is neutral, whereas in a Made-in-China World, the indication is toward local assembly. In a Free and Green World, I interpret it as companies can have some local assembly onsite per local content requirement while some pre-assemblies from abroad. In a Made-in-China World however, since the Chinese market is not open to outside players unless joint ventures are formed, assemblies and installation will have to be completely local.

For Europe, the responses from the two groups diverge completely. For the Free and Green World and Closed World scenarios, I tend to agree with the respondents from the industry network that assemblies should be largely local, for different reasons for the two scenarios. In a Free and Green World, Europe will continue to lead the industry through political and social support, being a destination of large-scale projects facilitated by already built or newly built port infrastructure, thereby allowing local assembly and installation. In a Closed World, Europe would have to rely on local assembly due to no cheap or available pre-assembly option from China. I align with the viewpoint of the sponsoring company respondents for the Made-in-China scenario where more pre-assembly is expected to happen abroad. Despite higher logistics costs, the overall low-cost thanks also to the high volume makes it still more economically viable to pre-assemble in China or elsewhere in Asia.

For the US, the picture is completely different and again the two groups hold opposite viewpoints. I align more with the sponsoring company respondents for the Free and Green World and Closed World scenarios in setting up a strategy for pre-assembly. For a Free and Green World, the market development in 2030 would outpace the port infrastructure development, resulting in some but still limited local final assembly options. For a Closed World, it is because few projects and lack of investment in port infrastructure would force the US to outsource pre-assembly probably from Europe or Asian countries other than China. In a made-in China world, I would argue for the response from the industry network members that the viable strategy is to localize assembly and installation. This is because cost reduction of the industry will increase its attractiveness and lead to infrastructure and vessel construction, thereby providing enough stage for local assembly.

There are more nuances to installation. As suggested by previous study (Maples et al., 2013), cost decrease can be achieved by diving turbine assemblies between onshore and offshore. Making changes to foundation and electrical installation approaches can also reduce cost. Another opportunity for cost reduction is to allow US work boats to transfer crew at a more significant wave height, from 0.9m to 1.5m, related to weather conditions.

6 Conclusion

As the offshore wind industry is in its early days, it requires a long-term view; scenario planning is identified as a suitable tool for supply chain strategizing. In this project, 12 key drivers for this industry are identified and ranked in terms of relevancy and uncertainty in order to envision three plausible and possible future scenarios: A Free and Green World, a Closed World, and a Made-in-China World. Respondents from the sponsoring company and the industry network suggested a variety of supply chain strategies spanning the areas of sourcing, construction, assembly and installation. The recommendations from this discussion are summarized below.

6.1 Insights and Management Recommendations

	Sourcing			Construction			Assembly/Installation		
	China	**Europe**	**US**	**China**	**Europe**	**US**	**China**	**Europe**	**US**
A Free and Green World	Invest / partner	Hands-off/delegate	Invest / partner	Vertically integrate	Sub-contract	Vertically integrate	Neutral	Local	Pre-assembly
A Closed World	N/A	Invest / partner	Invest / partner	N/A	Vertically integrate	Vertically integrate	N/A	Local	Pre-assembly
A Made-in-China World	Invest / partner	Hands-off/delegate	Hands-off/delegate	Vertically integrate	Sub-contract	Sub-contract	Local	Pre-assembly	Local

Figure 17: Summary of strategy recommendations

1) Sourcing strategy

The Closed World scenario will make operating in China not possible. The ideal sourcing strategy in China in both the other scenarios, a Free and Green World and a Made-in-China World, is to develop close supplier relationships and treat them as partners. In Europe sourcing can be delegated in a Free and Green World and a Made-in-China World, thanks to an established supplier base in both scenarios, whereas in the US sourcing can be delegated only in the Made-in-China World scenario.

2) Construction strategy

For construction in China, in either of the possible two scenarios, a Free and Green World or a Made-in-China World, it is recommended to vertically integrate a local manufacturing site. In Europe and the US, it is optimal to vertically integrate construction if 2030 turns out to be a Closed World. Otherwise, construction can be subcontracted, apart from the US leaning slightly toward vertical integration in a Free and Green World.

3) Assembly / Installation strategy

The assembly and installation strategy recommended for China in a Made-in-China World is local assembly and installation, whereas in a Free and Green World, it can be either local or pre-assembly depending on local content requirement. For Europe, the optimal strategy is to localize assembly in a Free and Green World and a Closed World, whereas if 2030 turns out to be a Made-in-China World, it is most advantageous to pre-assemble elsewhere. For the US, the optimal strategies are the opposite of Europe: in a Made-in-China World, assembly and installation are best to be local, whereas pre-assembly is preferable in a Free and Green World and a Closed World.

6.2 Future Research

The supply chain strategy analysis in this study has taken an overall approach, but future research can break it down to key component levels, with a focus on hull fabrication and wind turbine generators, as suggested by survey respondents. Another area of future research is to explore the possibility of China not providing a capable supplier base or relevant technology. Alternative methods such as transaction cost economics or system dynamics can also be explored, and results can be compared with the findings of this study. Furthermore, scenario planning can be carried out integrating more the effects of COVID-19 on renewable energy development.

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Appendix

Scenario Planning survey on Qualtrics

Scenario Planning Offshore Wind Supply Chain Strategy

Scenario planning is a tool for long-range forecasting. This survey is part of an MIT capstone project. It asks you to take the position of someone responsible for supply chain strategy for renewable energy deployment, specifically as an EPCI (engineering procurement construction installation) contractor constructing and delivering offshore wind farms. 3 plausible and potential scenarios are imagined and presented for 2030 for offshore wind and you are to choose what seems to be the most viable sourcing, construction and assembly/installation strategy for 3 markets today to prepare for that scenario in the future.

- Sourcing entails procuring key components including wind turbines.
- Construction entails constructing the platform, cables, substations, etc.
- Assembly and installation entails the final steps before commissioning the wind farm.

Offshore wind is an emerging renewable energy technology expected to be competitive with fossil fuels and solar photovoltaics in the next decade, to reach an average global levelized cost of electricity (LCOE) of $80 per megawatt-hour (MWh) (vs. $100/MWh for natural gas fired power) according to International Energy Agency.

Estimated response time is 10-15 minutes. Results are analyzed at an aggregate level (not individual).

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Scenario Planning Offshore Wind Supply Chain Strategy

What is your current position?

Years of experience in the energy sector?

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Scenario 1. A free and green world (open China)

China is open to a free and green world in 2030. The global community is committed to combating climate change through favorable policies for renewable energy development. National and regional governments not only fulfilled their stated policies as of mid-2019, targeting at least 10 GW of offshore wind construction capacity by 2030, but also went above and beyond to adopt more stringent energy policies for lower emissions, realizing the sustainable development scenario set by the International Energy Agency (IEA). World's total energy demand decreases as a result of declining oil and coal use, while renewable energy demand rises steadily.

Demand for offshore wind rises significantly across the globe, realizing its trillion-dollar investment potential into 2040 as claimed by IEA, allowing for a healthy project pipeline. Free trade means that suppliers enhance their capabilities to compete not only in local markets but also globally. Local content requirements are largely loosened. China increases its internal demand for offshore wind and allows sourcing from international suppliers. At the same time, Chinese turbine suppliers continue to improve their technology and assume more dominant positions in the global market. Yet Chinese component suppliers alone cannot fulfill the increasing global demand. Advancement of floating platform technologies opens new doors for more suppliers to enter the market. Especially in the US market, as port infrastructures are added, they expand capacity for and availability of local logistics operations. US suppliers emerge to build and operate Jones Act compliant vessels. (N.B. The Act from 1920 requires US port goods-transporting ships to be built, owned, operated by US citizens or permanent residents.) The EU continues to be an ideal location for both large offshore wind projects as well as mature component suppliers, supported by regional political efforts and collaboration especially driving operational excellence in transmission assets ownership.

What do you think would be the optimal sourcing strategy for the following markets if you are the company to build the offshore wind farms there.

- Hands-off / Delegate: delegate responsibility to suppliers, keeping few 1st-tier suppliers.
- Invest / Partner: develop strategic and close partnership with suppliers, engaging with many 1st tier suppliers.

Hands-off / delegate **Invest / Partner**

0 1 2 3 4 5

China

Europe

US

What do you think would be the optimal construction strategy for the following markets if you are the company to build the offshore wind farms there.

- Sub-contract: engage as many as external partners and suppliers to do construction.
- Vertically integrate: construct as much as possible in-house in local manufacturing facilities.

	Sub-contract 0	1	2	3	Vertically integrate 4	5
China						
Europe						
US						

What do you think would be the optimal assembly / installation strategy for the following markets if you are the company to build the offshore wind farms there.

- Local: assemble and install components as much as possible in local ports or offshore on the farm.
- Pre-assembly: pre-assemble and install components as much as possible before shipping to local ports.

	Local 0	1	2	3	4	Pre-assembly 5
China						
Europe						
US						

As general policy is considered here, would you treat any critical component differently? Any additional comments or insights about what you would do in this scenario?

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Scenario Planning Offshore Wind Supply Chain Strategy

Scenario 2. A closed world (closed China)

China is closed to the outside world, supplying and fulfilling only internal demand for offshore wind in 2030. Global trade wars hurt economies in developed countries. As Trump won a second term, US left the Paris agreement as planned resolutely on November 4, 2020, one day after the 2020 US president election, and thereafter more countries followed suit. The commitment to offshore wind development declined as countries lost budget for renewable energy projects. Not even the already stated policies (according to IEA's Stated Energy Policies Scenario) for climate change mitigation were realized and the momentum for clean energy technologies slowed down.

For existing offshore wind development projects in the pipeline in the EU and US, neodymium (made into NdFeB permanent magnets) as a key component for wind turbine generators becomes increasingly difficult to source from China for the US and US allied countries. China remains, as of 2020, to be the single source country where most of this rare-earth metal is mined. The closure of China forces the US to reopen its Mountain Pass rare earth mine which was closed as of 2019.

It is hard and almost impossible to deal with and source from Chinese suppliers as they become fully occupied with fulfilling local content requirements and the increasing local market demand. Local content requirements remain high in the rest of the world. The UK market has reached 86% of local equipment production earlier, and after Brexit in 2020 the local content obligation for all pipeline projects became even higher. Across the world the rise of populism continues, and less international trade results in stagnant economic growth worldwide.

What do you think would be the optimal <u>sourcing strategy</u> for the following markets if you are the company to build the offshore wind farms there. (Note: No China in this scenario, not possible to enter.)

- Hands-off / Delegate: delegate responsibility to suppliers, keeping few 1st-tier suppliers.
- Invest / Partner: develop strategic and close partnership with suppliers, engaging with many 1st tier suppliers.

	Hands-off / delegate 0	1	2	3	**Invest / Partner** 4	5
Europe				○		
US				○		

What do you think would be the optimal <u>construction strategy</u> for the following markets if you are the company to build the offshore wind farms there. (Note: No China in this scenario, not possible to enter.)

- Sub-contract: engage as many as external partners and suppliers to do construction.
- Vertically integrate: construct as much as possible in-house in local manufacturing facilities.

	Sub-contract 0	1	2	3	**Vertically integrate** 4	5
Europe				○		
US				○		

What do you think would be the optimal assembly / installation strategy for the following markets if you are the company to build the offshore wind farms there. (Note: No China in this scenario, not possible to enter.)

- Local: assemble and install components as much as possible in local ports or offshore on the farm.
- Pre-assembly: pre-assemble and install components as much as possible before shipping to local ports.

Local					**Pre-assembly**
0	1	2	3	4	5

Europe

US

As general policy is considered here, would you treat any critical component differently? Any additional comments or insights about what you would do

in this scenario?

Scenario Planning Offshore Wind Supply Chain Strategy

Scenario 3. A made-in-China world (China open out closed in)

China remains on target with its stated policy as well as sustainable development ambitions for offshore wind development. In 2030 it is on track with its plan to increase offshore wind installation capacity to 175 GW by 2040, and to utilize offshore wind to contribute to 5% of total for electricity generation by 2040. However the growth only benefits the local economy as stringent local content requirements make it extremely difficult for foreign competitors to set foot in project execution unless they have joint ventures with local companies. Such growth fuels the development of capabilities and technologies of Chinese supply chain, which is either vertically integrated into the developer-owner-operator companies or independent.

The booming local market also drives the learning curve, economies of scale and cost reduction for the Chinese component suppliers. This is especially true for the turbine manufacturers that become even more competitive. As of 2019, already five of the top ten offshore wind turbine manufacturers were from China. Following ambitious global expansion through low cost and satisfactory quality, they make eight of the top 10 list by the end of 2030, and plus they replace the dominant positions of Siemens Gamesa and MHI Vestas. Thanks to China's growth the cost of the offshore wind technology reduces significantly across the world, making it a more viable and sustainable choice for electricity generation in the US and EU and the rest of the world vis-à-vis other renewable technologies. Thus the industry grows internationally and in the long run local supply chains are developed in the main world regions.

What do you think would be the optimal sourcing strategy for the following markets if you are the company to build the offshore wind farms there.

- Hands-off / Delegate: delegate responsibility to suppliers, keeping few 1st-tier suppliers.

- Invest / Partner: develop strategic and close partnership with suppliers, engaging with many 1st tier suppliers.

Hands-off / delegate **Invest / Partner**

0 1 2 3 4 5

China

○

Europe

○

US

○

What do you think would be the optimal construction strategy for the following markets if you are the company to build the offshore wind farms there.

- Sub-contract: engage as many as external partners and suppliers to do construction.
- Vertically integrate: construct as much as possible in-house in local manufacturing facilities.

Sub-contract **Vertically integrate**

0 1 2 3 4 5

China

○

Europe

○

US

○

What do you think would be the optimal assembly / installation strategy for the following markets if you are the company to build the offshore wind farms there.

- Local: assemble and install components as much as possible in local ports or offshore on the farm.
- Pre-assembly: pre-assemble and install components as much as possible before shipping to local ports.

Local					Pre-assembly
0	1	2	3	4	5

China

Europe

US

As general policy is considered here, would you treat any critical component differently? Any additional comments or insights about what you would do in this scenario?

Scenario Planning Offshore Wind Supply Chain Strategy

Thank you very much for taking the time to fill out the survey!