The European electric bus market is charging ahead, but how will it develop?

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After China's successful deployment of electric buses (eBuses), with over 300,000 in operation today, widescale adoption of eBuses in Europe is near. Where European cities initially focused on pilot projects, now commercial roll-out is ongoing. Nonetheless, there is still a lot of uncertainty around eBus battery charging strategies and the optimal type of charging hardware, mainly related to costs and operational flexibility.

The main advantages of eBuses versus diesel alternatives are the environmental benefits in terms of exhaust emissions and air quality and the lower total cost of ownership (TCO). The lower TCO is a result of the lower cost per kilometer for running on electricity compared to diesel—although currently the battery cost still results in a higher overall acquisition price. Because of these benefits, governments are setting targets to accelerate adoption, such as The Netherlands mandating 100% sales of zero emission vehicle (ZEV) public transport buses by 2025, followed by 100% ZEV fleet by 2030, replacing all fossil fuel vehicles. At the regional level, cities, regions, manufacturers, and transport organizations endorsed a common ambition to accelerate the rollout of clean buses, formalized by the signing of the European Clean Bus Deployment Initiative. Besides battery electric buses, fuel cell buses are also considered clean when running on green hydrogen, but this article will not discuss this solution.

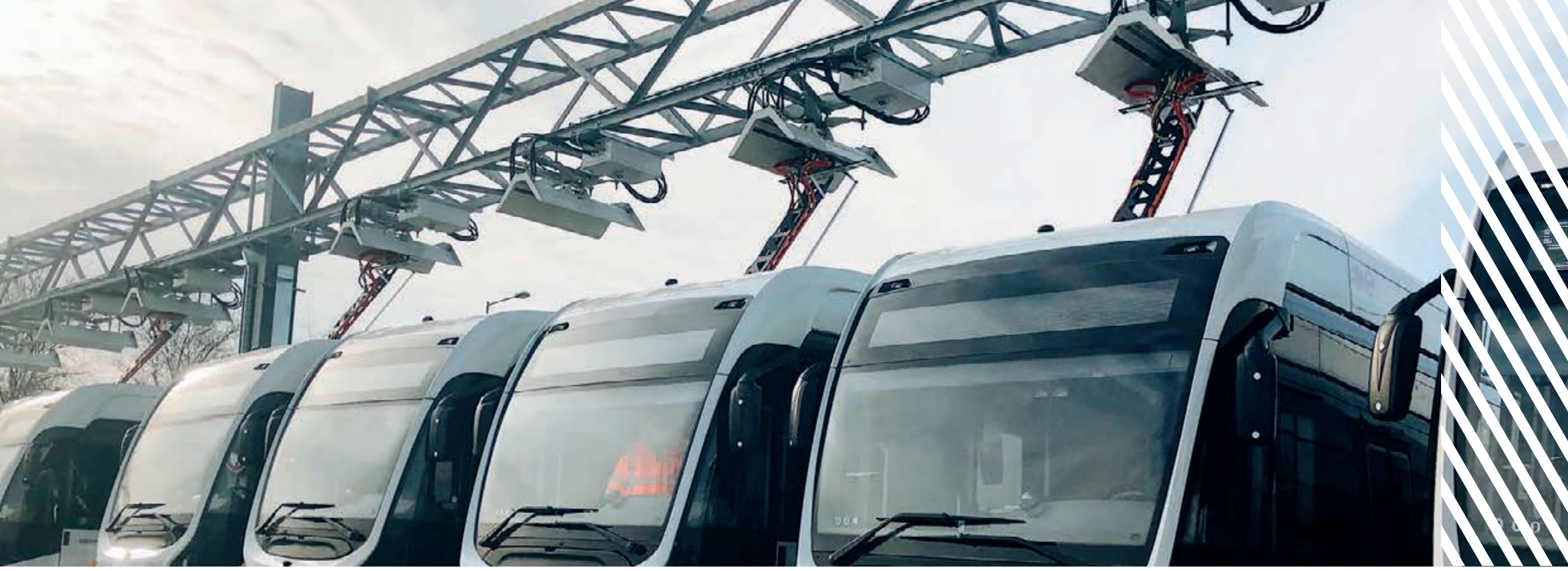
Since eBuses typically have a shorter range than diesel buses, one critical question that municipalities, transport operators, and manufacturers are still facing is where and when to charge them. This article compares the two main charging strategies: overnight charging only (depot charging) and recharging through the day (opportunity charging).

Public transport authorities and operators have the most influence on charging strategies

There are three main stakeholder groups in the eBus and charge point value chain: original equipment manufacturers (OEMs), public transport authorities (PTAs), and public transport operators (PTOs).

OEMs are heavily involved in eBus sales and tender processes, often forming partnerships with PTOs. OEMs of eBuses include BYD, Volvo, Solaris and VDL. Charging hardware companies include ABB, Heliox and Siemens.

PTAs (often semi-public) organize tenders for commercial players to operate public transport concessions for periods typically ranging from 10 to 15 years in their respective regions, and PTOs are the commercial operators that compete for these PTA tenders. PTOs choose hardware that best fits their needs (primarily cost-effective and reliable) and design the route network and schedules as per their contract mandate. The tender process is critical to the choice of charging strategy, as the PTA often pre-defines the strategy in the tender or gives credits to the PTO depending on their overall package.



Pantograph and plug-in solutions are expected to become key technologies for charging

There are two commonly-used strategies for eBus charging: Overnight charging (depot-only charging), and overnight plus daytime recharging (opportunity charging).

Opportunity-only recharging is not workable yet for eBuses due to technical and practical requirements, including the balancing needs of batteries. Often, chargers used for overnight charging (typically 30-50kW) are referred to as "depot chargers", while superchargers (150+kW) are referred to as "opportunity chargers". However, when using an opportunity charging strategy, charging at depot is also required overnight.

There are three main technical options for the physical charging of eBuses (plug-in, pantograph, and induction), and the best option depends largely on the type of charging strategy employed. Depot-only strategies are mainly plug-in, because it is the simplest option requiring the least additional equipment. For opportunity charging, however, pantographs (where the eBus is linked by wire to a power source, similar to tram systems) are most common. Induction, where a contactless electromagnetic field charges the eBus, is currently more expensive (including acquisition, efficiency, and maintenance costs) and more difficult to operate than the other two options.

There is no standardized technical solution for pantograph charging yet, but there are two popular options: pantograph-up and pantograph-down (see exhibit 2 overleaf). Some players are currently championing one solution (e.g., Volvo and ABB for pantograph-down), while others adopt both technologies. As both systems have their own advantages, they can and will potentially co-exist.

There are three main technical options for the physical charging of eBuses: plug-in, pantograph, and induction

Exhibit 1

Main differences between opportunity and depot charging

Source: McKinsey Energy Insights

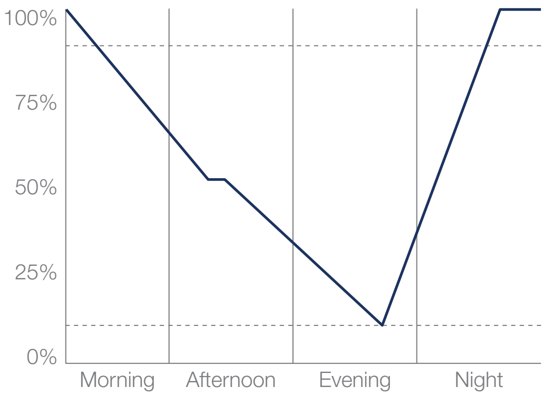
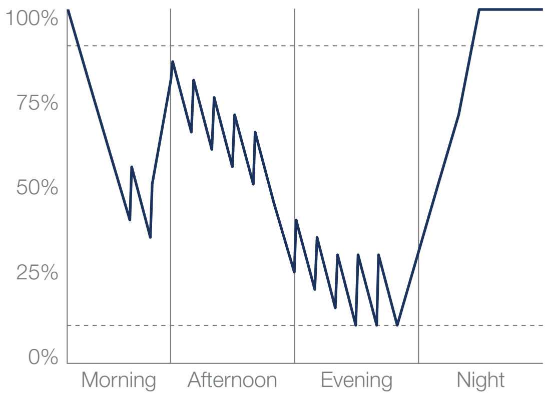
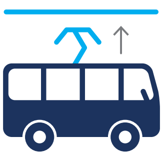
Strategy	Depot Overnight only	Opportunity Overnight and mid-day recharging
Charger type	Depot: 30 up to 150 kW (for buses with high range)	Depot: 30-50 kW Opportunity: 150/300/450/600 kW (e.g. at end-stop or terminal)
Charging technology	Mostly plug-in	Mostly pantograph Plug-in (less common) Induction (less common)
Load profile (illustrative)		
Typical range	100-250 km/day	200-500 km/day
Cost drivers	**1** Higher battery cost **2** Lower charging infrastructure cost, unless an expensive depot charger of 100+ kW is required to fully recharge during night (instead of cheaper 30-50 kW)	**1** Lower battery cost **2** Higher charging infrastructure cost **3** Slightly higher maintenance cost

Exhibit 2

Two pantograph solutions have different advantages

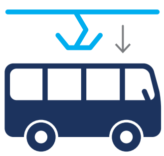
Pantograph up
Roof mounted (CCS)



Bus connects to charger, with communication over CCS

- No WiFi connection required because driver initiates charging
- Connection follows existing CCS standard
- Only one bus out of order in case of pantograph failure
- Maintenance similar to that of trams and can be completed at the depot, enabling PTO personnel to carry out maintenance procedures

Pantograph down
Pole-mounted (OppCharge)



Bus requests connection via WiFi, so that pantograph can connect to bus

- Lower weight of system, especially helpful if bus is at maximum weight limit (e.g. with battery capacity)
- Lower height of bus, which enables it to pass under low-clearance bridges
- Lower cost of installation per bus, as fewer pantographs are required

Source: McKinsey Energy Insights, expert interviews

Considerations for combining or splitting tenders for bus and hardware

There are no established standards for charging infrastructure at the moment, so tenders for bus and charge points are often combined to ensure compatibility.

Once standards are defined, the tenders could be split, which would increase system flexibility—allowing more competition and thus lower pricing. Another advantage of split tenders is that charging hardware has a longer lifetime than buses, so cost effectiveness increases when they are bid separately. This is partly addressed by PTAs who are already extending concession periods to 12-15 years. Currently, the PTO picks the eBus brand and charge points, which can create lock-in because the concession holder is always best positioned when the time comes for contract renewal. At the same time, single responsibility ensures optimal system functioning and more clear responsibilities.

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Cost analysis of opportunity versus depot charging shows different winners depending on daily distance

To analyze the cost effectiveness of charging strategies, different types and distances of the eBus route need to be considered, reflecting different needs and technical feasibility.

We chose four types of routes for our analysis, including short distances of about 150 km/d, along with medium-distance city and medium-distance rural routes, both of which are 300 km/day, but with respective route lengths of ~12 and 30 km from start to end. The fourth category is long-distance routes of about 450 km/d.

The major costs that differentiate the two charging strategies are battery cost and charger cost

The major costs that differentiate the two charging strategies are battery cost and charger cost. Power prices can also vary depending on the time of day and volume purchased, but that depends on local market conditions. Both battery and charger costs are falling and are expected to continue to do so, thanks to technological advances and increasing economies of scale. Other parameters, like the chassis cost of the vehicle and bus drivers, are irrelevant for this comparison of charging strategies (unlike in the comparison with diesel alternatives).

Our cost analysis shows that for short routes, depot charging is more economical, while for longer routes the balance flips toward opportunity charging (see exhibit 3).

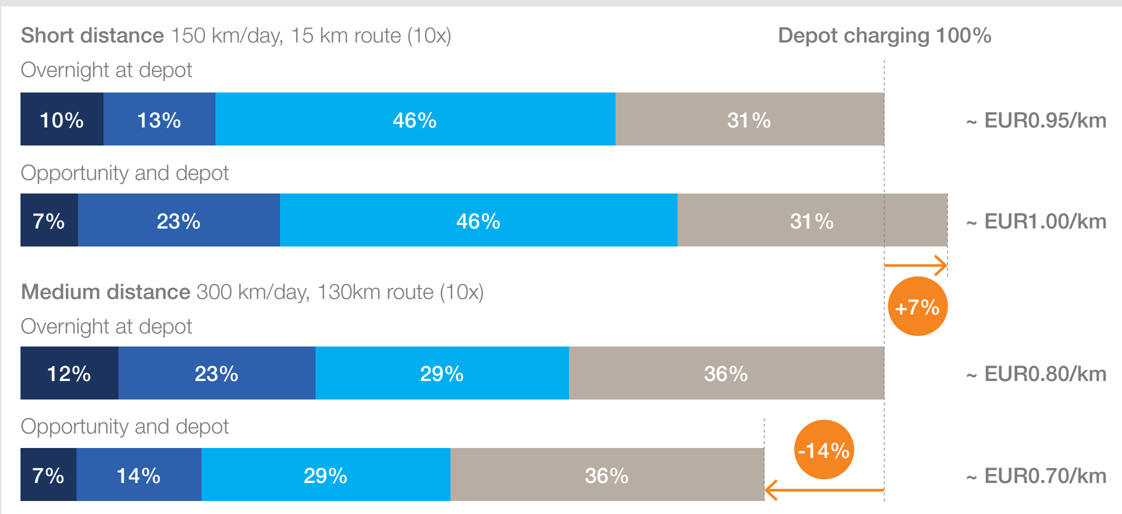
For short routes, we estimate that depot charging is 5-10% cheaper than opportunity charging, as the battery is relatively small and a 50-kW charger is sufficient. In this analysis, the cost of the bus driver—which can make up to two-thirds of the total TCO—is excluded. As a result, the complete cost differential is relatively small. For longer routes, opportunity charging saves 10-20%, as it enables a significantly smaller battery and a lower-cost charger at the depot. In order to recharge a battery with 300+ km range, a simple 50-kW charger is sufficient when combined with opportunity charging, while depot-only charging would require a more expensive 150-kW charger. The optimal speed for opportunity charging (e.g., 150 or 450 kW) depends on the total daily driving distance and stopping time en-route. As the cost of batteries is projected to decline at a similar rate to charging points, the cheapest charging strategy is not expected to change over time.

The above conclusions are based on analysis of an 'average' route, but specific local circumstances, such as weather, topography, and utilization of chargers, can change the outcomes. Cold winters or hot summers, as well as elevation gains on routes, can significantly increase electricity consumption and thus warrant a bigger battery and drive up the associated cost, strengthening the case for opportunity charging.

Higher utilization of chargers can also bring costs down, so if several eBuses are scheduled on one route, it lowers the cost per bus of charging points. Conversely, this makes quieter routes more expensive for opportunity charging, tipping the scales in favor of depot charging.

Exhibit 3

Total cost of ownership comparison of charging strategies



- Battery
- Charging equipment
- Other Capex (including bus chassis)
- Opex (excluding driver)

Source: McKinsey Energy Insights

While PTOs are very cost conscious, there are a few reasons why they could deviate from the most cost-effective option

Charging strategies will not only be selected based on cost

While PTOs are very cost conscious, there are a few reasons why they could deviate from the most cost-effective option.

Most importantly, local factors such as weight limits and planning considerations could restrict charging options. Battery weight (and therefore depot charging) can be constrained by old bridges and similar obstacles, requiring opportunity charging to reduce weight. On the other hand, urban planning can mean limited space for opportunity charging, restricting eBuses to depot charging only, despite the higher cost.

Furthermore, early charging strategies will be dictated by eBus supply and standardization. Over the next three years, for example, early movers like Chinese BYD could continue to dominate the eBus market, with buses that currently do not support opportunity charging.

Finally, some PTOs prefer the flexibility to operate eBuses on different routes, so they are unlikely to optimize their charging strategy based on individual routes. This means even short routes could use opportunity charging, especially if the charging points used are going to be installed for the longer routes anyway.

Conclusions and implications

Our analysis shows a clear TCO advantage for opportunity charging on longer routes (>150 km/day), while shorter routes can be run most economically by using depot-only charging.

This trend is expected to remain unchanged, because the main cost drivers—battery cost and charging hardware—have similar declining cost projections. However, operators can still opt for a less economic solution for non-TCO reasons, such as restricted operational flexibility.

As a result, we expect a mix of both solutions to prevail. Translating the strategies into a market for depot chargers and opportunity chargers, the amount of depot chargers will be significantly larger, with the main reason being that for opportunity charging strategies a depot charger is still required overnight.Furthermore, opportunity chargers are often shared amongst multiple eBuses, resulting in a lower installed rate and lower purchases of opportunity chargers.

While the quest for the most optimal charging strategy is most relevant to PTOs and PTAs, there are also implications for other stakeholders, ranging from OEMs and governments to utilities and oil companies. All those involved need to ask themselves a number of questions in order to ensure they are well positioned for the eBus roll-out (see exhibit 4 overleaf).

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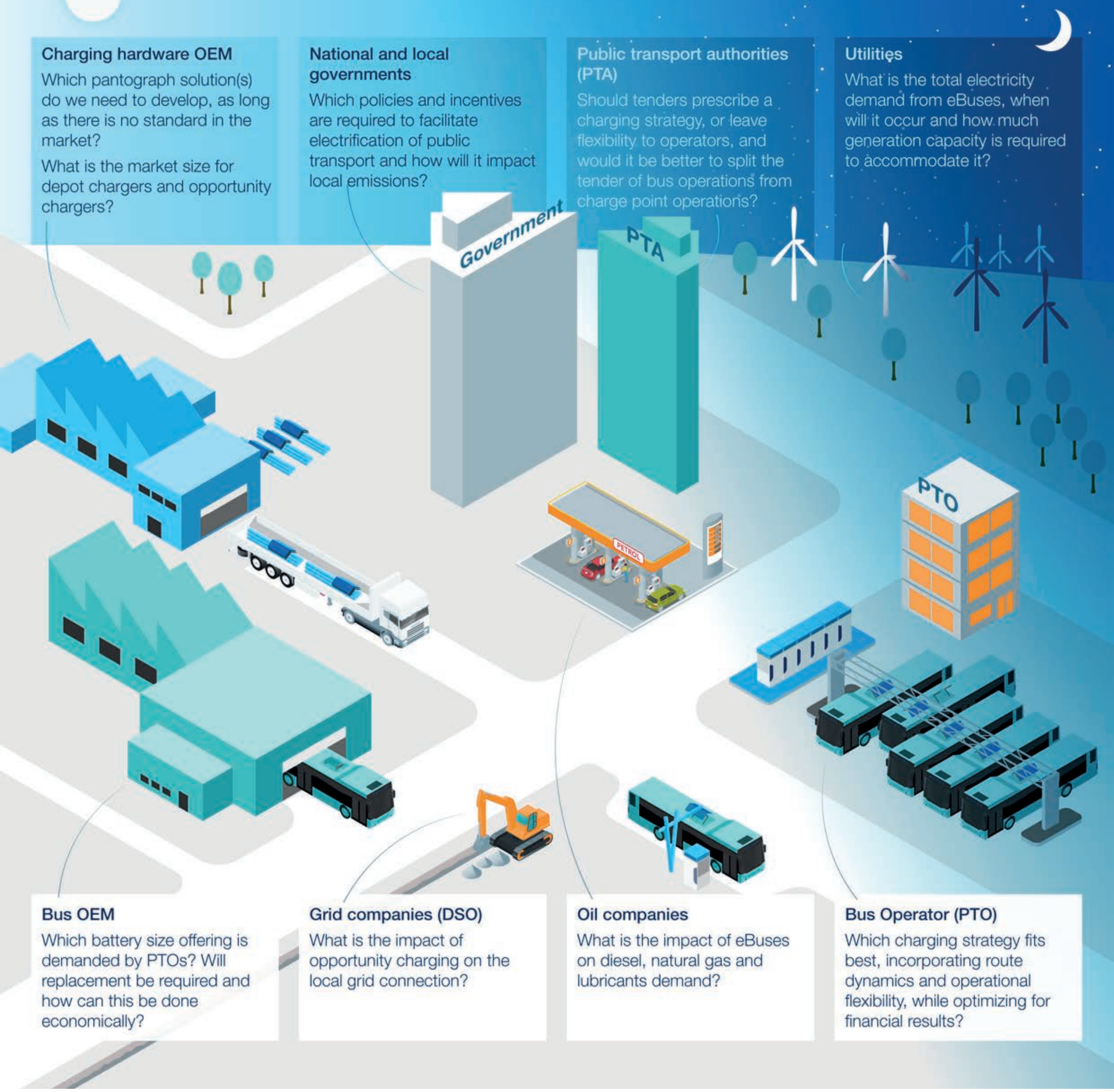
Exhibit 4 Key questions for stakeholders

Source: McKinsey Energy Insights



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