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Working Paper

Securing decarbonized road transport – a comparison of how EV deployment has become a critical dimension of battery security strategies for China, the EU, and the US

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Securing decarbonized road transport – a comparison of how EV deployment has become a critical dimension of battery security strategies for China, the EU, and the US.

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Securing decarbonized road transport – a comparison of how EV deployment has become a critical dimension of battery security strategies for China, the EU, and the US.

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Summary

This paper compares how the pursuit of self-sufficient Lithium-ion battery production by the three main geo-economic players (China, the European Union, and the United States) is unfolding by looking at the electrification of the transport sector. The analysis of this paper uses the concept of energy security and the 4 As outlined by the Asia Pacific Energy Research Center (2007) to outline the availability, accessibility, affordability, and acceptability of Lithium-ion (Li-ion) batteries for each respective actor. This paper aims to compare the dynamics of each geo-economic player's EV deployment along these four indicators. Most work in this field assesses the battery strategies of these three geo-economic players individually or focuses on EV deployment from a purely economics perspective. In contrast, this paper attempts to bridge this gap through the framework of energy security to compare how each of the three player's battery strategy connects to broader EV deployment. Adopting this framework allows us to highlight how China's strong industrial policies and generous incentives contrast to the government multilateral alliance-building done in the European Union and the overwhelmingly dominant role of private actors found in the United States.

This paper is part of a series of working papers comparing the climate and energy policies of China, the European Union, and the United States to better understand the geopolitics surrounding global decarbonization.

Keywords: Lithium-Ion Batteries, Electric Vehicles, Energy Transition, Energy Security, China, the European Union, the United States.

JEL Classification: Q48; Q30; F59

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1.0. Introduction:

As the climate crisis continues to worsen, major economies are developing decarbonization strategies. While these plans target a suite of technologies, they give special attention to batteries because they are key for unlocking deep emission cuts. Not only can they enable deep penetration of renewables into the power sector, but they also extend the possibilities of electrification to sectors currently dominated by fossil fuels. Transportation is one of these sectors, as it operates primarily on oil derivatives for energy. Decarbonizing this sector, especially road transport, will almost wholly rely on electric vehicles (EVs) – which will require a lot of batteries. This trend is already on the upswing, and EV deployment is accelerating rapidly worldwide. As a result, transport appears to be the first place where batteries will be adopted at scale. This paper acknowledges this and focuses on analyzing EV deployment as a proxy to identify trends in the geopolitical competition over battery technologies. We will focus specifically on Lithium-ion (Li-ion) batteries because they account for the substantive majority of all batteries used in EV's.

The overlap between the automotive and battery industries is a natural source of fierce geopolitical competition because both are highly strategic. A strong automotive sector is the hallmark of national power. It signifies that a given country has an industrial base capable of producing high value and complex manufactured goods that are desired globally. It also creates domestic jobs, a skilled workforce, considerable economic activity, and spurs investments into innovation. The battery industry mirrors many of these aspects, but it is not yet at the scale needed to match where the market is headed. However, policymakers realize that if they want to secure a decarbonized future, they will need a large volume of high-quality batteries. This realization is driving leaders to secure a national competitive edge while shoring their vulnerabilities against rivals.

Economics plays a certain role in this logic because batteries are a high-value input, and their expected scale, in and beyond EVs, is an enormous economic opportunity. However, questions of national security are rising in importance because battery production capacities are not dispersed. They remain highly concentrated within a few specific companies clustered predominantly in East Asia. Such concentration inadvertently leads to the problems of monopolies – or oligopolies – and import dependency. This is particularly problematic for countries with strong automotive sectors because the backbone of national manufacturing could come to a halt if this input were obstructed. Additionally, batteries also represent the component with the highest value-added in each EV, making it the most sought-after input in the EV value chain. Leaders are pushing for self-sufficiency in battery production to secure the integrity of their own energy transition and domestic automotive sectors to address these concerns.

While many countries are following this path, the three most significant actors will be the People's Republic of China (PRC), the European Union (EU), and the United States (US). Geopolitical

tensions are increasing between them, and each is trying to take leadership over the industrial revolution climate policies will bring with it. Beyond this, these three economies represent almost half of global emissions and the bulk of GDP. They are also projected to be central to global battery production. China is already the dominant actor – having cornered roughly three-quarters of global production in 2020 (Moore, 2021). While the EU & the US combined represent just below 15% of global production, they have set strong policies and are projected to considerably increase their production capacities and double their relative global share by 2030 (Ibid). At the same time, these economies have strong automotive sectors and huge auto markets that will be the core of global EV deployment. Chart 1 shows the IEAs projections for the annual EV battery demand by region and scenario between 2020 and 2030. In both the stated policy scenario¹ (SPS) and sustainable development scenario² (SDS) these three economies represent most of the projected global demand at both time intervals. This reaffirms why focusing on these three economies are important for analysis.

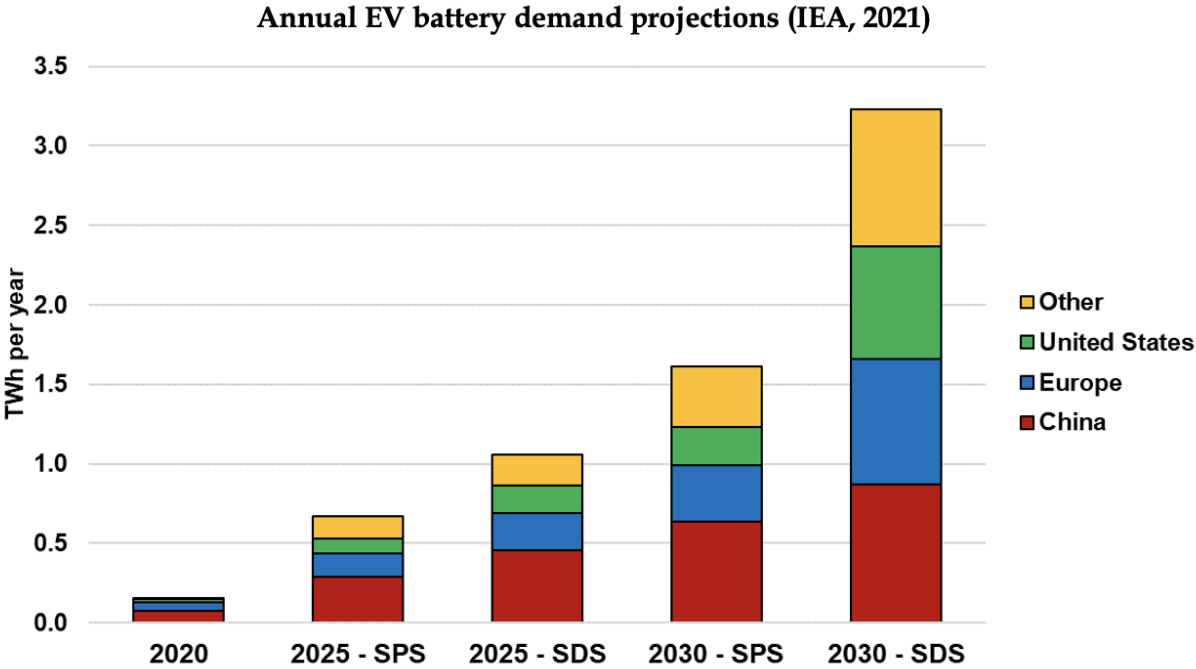


Chart 1 – Annual EV battery demand projections by region and scenario, 2020-2030 (Data from International Energy Agency *Global EV Outlook 2021*).

While previous studies have assessed the self-sufficiency strategies of these geo-economic players, they are rarely compared because the aim is usually to identify threats posed by foreign

¹ The SPS is a conservative model that projects future outcomes based on concrete policies that are either announced or in place. It does not consider that countries will reach their targets.

² The SDS is a model that projects future outcomes based on both policies and realized pledges. This model assumes that countries will reach their net zero-targets.

dependence on a specific actor. Moreover, studies of the transport sector tend to focus on broader EV deployment through a purely economic perspective – which underappreciates strategic implications. To fill this gap, this paper explicitly focuses on comparing each actor while attempting to move beyond a solely economic analysis. Based on the conceptual framework for energy security outlined³ by the APERC (2007), the paper will assess the four A's – *availability, accessibility, affordability, and acceptability* – behind batteries through the proxy of EVs. Doing so will allow us to compare how the EV market of each actor developed and how they are becoming a strategic aspect of national energy security. To this end, our analysis intends to answer the research questions of *how has each actor used national policies to secure demand and supply for EVs? how does the national battery strategy of each actor interact with their efforts to electrify transport? and how does this impact their strategic framework on energy security?*

To answer these questions, this paper starts in section 2 by overviewing how the conceptual framework of energy security connects to batteries and EVs. Section 3 will apply this framework to assess each economies self-sufficiency strategy and its interactions with the ongoing electrification of transport. Section 4 will compare and discuss the implications of each strategy before concluding in section 5.

This work is part of a series of FEEM working papers assessing the geopolitics of the global energy transition between China, the European Union, and the United States. Other working papers in this series deal with the decarbonization of power sectors based on historical data (Noussan et al., 2021), climate and energy governance (Lu et al., 2021), just transition policies for coal industries (Zhu et al., 2021), the security of rare earth minerals (Raimondi et al., 2021) and power battery security presented in this paper.

2.0. Connecting Energy Security to Batteries and EVs

The concept of energy security emerged to prominence during the first oil price crisis in 1973. While the concept has since moved beyond oil to encompass energy more broadly, the focus on securing energy has still become a cornerstone of government policy. At its more fundamental level the concept can be defined as the “*protection of the entire energy supply chain and infrastructure*” (Yergin, 2006, p. 78). Yergin emphasises the physical security of an *available* energy resource flowing through a supply chain to become *accessible* to a consumer. These two A's outline the concepts dimension of *security of supply*, which can be understood as a departure from the consumer perspective,⁴ wherein the consumer is taking actions or policies to ensure that they have access to sufficient energy to meet their needs. If we depart from the producer perspective,

³ This concept was chosen because it can bridge the gap between economics and strategic realities without losing track of the core goal of decarbonization. The 4As were utilized because they operationalize this concept in a robust and accessible way.

⁴ When considering energy security, it is important to consider the perspectives of energy importers, exporters, and transit states. The country's perspective changes from a security of supply to security of demand or security of transit.

this becomes *security of demand*, whereby a given supplier's *available* resources are made *accessible* to consumers in a way that rewards the investment. The primary way to achieve security of demand or supply is to diversify your energy portfolio⁵ to avoid total dependence on any specific point within the supply chain. There are many ways to achieve this, but generally it can be achieved by having multiple energy consumers, suppliers, sources, and routes to call upon (Yergin, 2006; Jakstas, 2020; Sovacool et al., 2012).

As the concept further evolved, it adopted the 3rd A – *affordability* – which focuses on the economic rationale of reliably delivering an energy resource at a reasonable cost to consumers and producers. The focal point here is the importance of having a well-functioning market that can efficiently allocate resources to deliver the most competitive energy sources. Doing so while maintaining price stability is essential because price volatility lowers the confidence of both consumers and producers. Lack of confidence in energy prices can cause severe economic damage because energy consumption is still invariably linked to economic output. Accordingly, if the energy price is too high or volatile, then the economy slows down because economic output becomes disrupted.

In a more recent turn, the concept has moved towards the 4th A – *acceptability*. To a certain degree this can be considered an energy sources' social license to operate from those consuming it. An example of this is the global push against coal because of its emission intensity. This unacceptability has resulted in steps taken to push it out of the energy system. Social licences are tricky because they depend on the reference community, and an agreeable source somewhere may not be accepted elsewhere. This can give preference to an energy source, even if it is self-detrimental. Such rhetoric can be seen in the US, where prominent politicians discourage renewables because they cost fossil industry jobs and the technology is made overseas (i.e., in China). This example directly contradicts the previous example and illustrates that acceptability is fundamentally a political dimension that influential political opinions can structure.

By considering the *availability*, *accessibility*, *affordability*, and *acceptability* (the 4 A's) of energy security we follow the conceptual focal points identified by APERC in their 2007 report (Intharak et al., 2007). However, these 4 A's are by no means exhaustive, and there are certainly different ways to approach the concept other than this (see Cherp & Jewell, 2014). Nevertheless, by looking at the 4 A's we have a level of analysis that is easily accessible to policymakers while remaining reasonably comprehensive. Even on this level, we can see that the concept of energy security is complex and dynamic. The energy concerns of the past have certainly not disappeared, but decarbonization and climate change bring new complexities to the fore. We can see how each of

⁵ Some would argue that energy independence through self-sufficiency is a better way to secure supply than diversification because you directly control the resources. However, total independence is virtually impossible for most actors, and at the same time, extreme self-sufficiency creates the vulnerability to gaps within your own system. The 2021 winter blackout of the Texas power grid is a good example of the problems with this approach.

the 4 A's compete with one another and how managing the competition of these policy priorities is complex as governments need to consider all four dimensions in conjunction when setting national energy policies⁶. In recognizing this complexity, modern energy security can be considered as a set of policies that aim to secure uninterrupted and timely access to the volumes and quality of energy needed to sustain growth without relying on suppliers and sources that are economically, environmentally, and socially unacceptable to consumers.

Balancing this is tricky across multiple energy sources and sectors because it is hard to prioritize one over the other. Difficult trade-offs exist and governments might be forced to favour one dimension over another in the short term; however, they should all converge in the long run. Under normal circumstances policymakers adjust this according to which fuel input can reasonably substitute one another without causing disruptions. However, this is hard for the power sector because electricity cannot be substituted in most applications. While other energy inputs – like gasoline – are also hard to substitute, power is different because it is both an essential good and service. Not only it is consumed as a good for economic output, but it is also used as an essential service that enables the necessities of modern life (i.e., lighting & refrigeration). This makes power security important because decarbonization will dramatically increase electrification. As this occurs, sustaining the power sector will become the most crucial dimension of energy security as a disruption could instantly impact the entire economy. This is because all the other energy ecosystems currently relying on fossil energy sources – heating, cooking, transportation, and portions of industry – are expected to eventually become electrified and dependent on a secure power grid.

The growing importance and complexities of clean power systems inadvertently elevate batteries and other energy storage technologies into the energy security discussion. To truly decarbonize we need widespread deployment of renewables, but renewables depend on supporting technologies to make them a secure and flexible resource. The scenarios tested by Coester, Hofkes, & Papyrakis (2020) reinforce this, as they found that renewables in Germany had limits to their levels of integration without storage. However, they also highlight that government support of battery usage could help continue renewable deployment while also ensuring that power supplies are not interrupted during the transition. Mountain & Percy's (2021) report builds on these findings to show that batteries' role in securing Australia's power grid is rising: In Q4 of 2020, batteries and demand side response were 38% of the frequency control market in Australia, despite being only 0.5% of the power grid's total generation capacity. Their work also finds that the 350 MW battery being developed by Energy Australia will provide over 300% more inertia to the power system than what is provided by their 1,480 MW coal plant. Other applications in the American military show that renewables with batteries and microgrids could reliably meet

⁶ This is referred to by the World Energy Council (2021) as the energy trilemma of affordability and access, energy security and environmental sustainability.

critical loads while making facilities considerably more resilient to extreme supply disruptions (NREL, 2021). In larger-scale applications, the flexibility of batteries also allows off peak production to be stored and used during peak demand. The smoother load curve helps improve security by reducing the stress power systems experience from rapid fluctuations in production and demand.

Azzuni & Breyer (2018) take a more comprehensive approach explicitly connecting batteries and other energy storage systems to energy security. Their work finds that all storage technologies improve energy security but that some – like batteries – had particularly strong positive relationships with energy security. They highlight batteries as incredibly flexible technologies that can be widely deployed across various applications with relative ease. At the same time, the technologies themselves are durable and constantly improving on both cost and quality. The cumulation of this translates into a highly secure technology because it is available, accessible, and increasingly affordable. Interestingly, these authors also flag batteries as politically acceptable because domestic battery production results in local manufacturing jobs.

The NAATBatt International (2021) expand this, emphasizing that domestic production of batteries is the primary medium to resolve energy securities concerns with the security of battery supplies⁷. Pursuing self-sufficiency for such advanced technology as batteries is complex though. It requires a robust industrial base capable of highly advanced manufacturing and a deep financial commitment to bring production to scale while advancing expensive cutting-edge research. These requirements are similar to the prerequisites of a strong automotive industry, and this overlap creates an opportunity. Whereby countries with strong auto sectors can leverage their existing industrial apparatus to bring cutting-edge technology to scale while also decarbonizing and reducing dependence on oil in the transport sector. The combination these aspects is one of the reasons why EVs are where batteries will see their first wide scale deployment. Nevertheless, this has induced a conversation about dependence on batteries for manufacturing and security of energy transitions. This paper explores this linkage and uses the policies supporting the deployment of EVs as a proxy to identify trends of how strong domestic battery industries are becoming an important dimension of energy security. This paper discusses EVs as a category encompassing battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). In certain instances, differences will be noted – but in general policies supporting BEVs also support PHEVs, albeit often to a lesser extent. Additionally, while fuel cell electric vehicles (FCVs) and other zero-emitting vehicles (ZEVs) are a part of this conversation, they are currently a much smaller part of the picture in decarbonizing transportation and not considered here.

⁷ To an extent, this is true; however, when considering battery manufacturing it is imperative to consider the materials composing the batteries. Most batteries require substantial volumes of critical minerals with geopolitically charged supply chains. While this issue is important for battery security, we address securing access to critical minerals in more detail in another working paper of this series (see Raimondi et al., 2021).

3.0. The Role of Batteries in Decarbonizing & Self-Sufficiency

3.1. The People's Republic of China

3.1.1. China's Traditional approach to energy security

Since the Sino-Soviet split induced severe energy shortages in China in the 1960s, Chinese energy security has been ideologically framed through the Maoist doctrine of development through self-reliance (自力更生) (Downs, 2000). Although this does not disbar cooperation with foreign actors, it does imply that retaining complete decision-making power over the national energy system is an ideological imperative for the central government. However, this has been a logistical challenge because China's energy consumption for every input has grown so rapidly. From 1980 to 2019, total energy consumption increased by 770%, with coal rising by 677%; oil by 701%; natural gas by 2143%; and power by 2599% (EIA, 2021a). Even though China has a substantial wealth of domestic energy resources, it could not scale production to match consumption growth. The result has made self-sufficiency virtually impossible without relying on imports. While import dependence can be manageable, China relied on imports for 72.5% of its oil and 40.6% of its natural gas consumption in 2019 (IEA, 2020).

In conjunction with the energy-intensive nature of the Chinese economy, these high values are why Beijing focuses on the supply-side of energy security. This indicates that the Chinese government's core concern is guaranteeing that their country has unfettered access to sufficient volumes of the energy resources needed to continue developing their economy and society. There are two significant threats to this, one external and one internal. The external dimension is the threat of a major supply disruption on imports. Beijing has been proactively addressing this by diversifying supply routes through neighbouring countries, increasing strategic reserves, and nationalizing major parts of the import supply chain. Despite this, China remains inescapably vulnerable to unlikely extremes – such as an American naval blockade (Tata, 2017) or heavy sanctions (Meidan, 2019). The internal dimension of managing the domestic energy system is arguably the more practical concern because while external disruptions have severe repercussions, they are infrequent, whereas internal disruptions from policy mismanagement occurs regularly.

Certain dimensions of the power crisis China experienced in the fall of 2021 was a primary example of this⁸. Other examples can be seen in the redundancy of gas transmission infrastructure⁹, or the large-scale curtailment of renewable generation¹⁰. Beijing has taken steps

⁸ In the fall of 2021, multiple regions of the Chinese mainland experienced prolonged periods of power disruptions. While many factors contributed to the shortfalls, a significant driver was the central government's usage of indexed power prices that could not account for rising coal prices. As coal prices climbed power plants were obliged to sell electricity for less than the cost of producing it. Many plants rejected this choice, instead choosing to shut down operations. This policy failure resulted in severe power shortages.

⁹ During the rapid buildout of natural gas infrastructure in China, several major state-owned enterprises built long string pipelines adjacent to one another. They essentially did this to sell to customers across the country while avoiding sharing pipelines.

¹⁰ In the mid 2010s, China was deploying renewables so rapidly that the grid could not integrate the generated power.

over the past several Five-Year Plans to rationalize the national energy system (see Constantin, 2005 and Stanley Foundation 2006). While this entailed many targets, the macro trend was to make the energy system more efficient. Part of this was to make consumption more economically valuable by moving energy usage away from low-value energy-intensive industries to sectors where energy consumption adds substantive value. Other aspects were related to reforming the business models of national grid companies by introducing new pricing tools (Fishman, 2021) and heavily reducing overcapacity in the coal fleet (see Zhu et al. (2021) in this working paper series for more insight).

3.1.2. The role of batteries in decarbonization and self-sufficiency strategy

While China is currently the world's largest producer of greenhouse gases, its transportation sector accounts for a modest portion of this. In 2016, transport was responsible for 843.5 Mt or about 7.2% of the cumulative 11.62 Bn t CO₂e emitted by the PRC that year (Ritchie & Roser, 2020). Nevertheless, these emissions have grown by over 800% from 1990-2016 (Ibid). The increasing mobility for China made it the world's largest car market in 2009 (Naidu-Ghelani, 2013), and by 2020 Chinese consumers bought 20.18 million light duty vehicles (LDVs) – roughly 37.6% of global car sales (OICA, 2021). These figures are only expected to grow because China is a developing economy still connecting hundreds of millions of people in rural areas to quality transport. In other words, China's transport emissions will continue growing, which is a challenge if China intends to peak emissions before 2030 and cut them afterwards - unless there is a strong focus on electromobility.

Battery powered vehicles are central to this and to the *dual carbon goals* – of peaking emissions before 2030 and becoming carbon neutral before 2060 – announced by President Xi Jinping at the 2020 United Nations General Assembly. Not only can they help sustain societal development, but they can also curb transport emission growth and reduce local air pollution within major cities¹¹ because new energy vehicles (NEVs) produce no tailpipe emissions. The Chinese government uses the term NEV as a broad term to collectively account for BEVs, PHEVs and fuel FCVs. The Chinese recognize the value of NEVs¹², and the *Made in China 2025* (中国制造 2025) strategy attaches significant value to a strong battery industry as the basis for a strong NEV sector. An interpretation of this strategy from the Ministry of Industry and Information Technology (MIIT) outlines how an automobile industry built around NEVs is the only way China can become a powerful automobile manufacturing country (MIIT, 2016).

These documents highlight how the age of the internal combustion engine (ICE) was dominated by American, European, and Japanese firms which used their technical prowess to export vehicles

¹¹ The introduction of NEVs within Chinese cities has been shown to deliver considerable improvements to local air quality if done at scale. This can yield considerable benefits to local public health and economic activity (Ma, Madaniyazi & Xie, 2021).

¹² In the context of this paper, BEVs and PHEVs are the focal point when referring to China's NEV policies.

globally. The MIIT (2016) sees the auto industry as a 'strategically competitive industry' and notes that, while the Chinese industry is large it is not strong enough to compete globally in the ICE market with its established counterparts. Hence, NEV's become attractive. It is a future technology that in the 2010s was being ignored by all major competitors, and if China moves early, it can secure a technological lead. This will allow the Chinese auto sector to outcompete foreign vehicles domestically and even give it the competitive edge to export high value-added batteries and EVs to advanced economies. This is particularly important because China will continue to be the world's largest auto market well into the future, and reducing imports here pushes high-value purchases from Chinese consumers to domestic suppliers. Likewise, by increasing EV's in transport, Chinese leaders can also indirectly substitute oil imports consumed by ICEs with domestically produced power and simultaneously tackle air pollution (Hove, 2017).

3.1.3. Availability & Accessibility of EVs in China

To successfully build out the battery and EV industry, China needs to create a market with a secured demand and secured supply. The first major attempt to secure demand was to leverage the substantial volume of Chinese government procurement. This was launched in January 2009 through the *Ten Cities, Thousand Vehicles* pilot program (十城千车工程) that subsidized the use of EV's for public procurements¹³ in ten major cities (Xinhua News Agency, 2009). This included taxis, buses, and other public services vehicles. Two months after this pilot started, the State Council (GOSC, 2009) released the *Plan on Adjusting and Revitalizing the Auto Industry* (汽车调整和振兴规划) that set the target of reaching 500,000 EV sales by 2011. While this pilot eventually extended subsidies to private purchases in a few cities, the policy focus and most sales remained through public procurement (Hao, Ou, Du, Wang & Ouyang, 2014). By 2012 this policy had only achieved 38% of the targets (Ou et al., 2017). It can be expected that the initial exclusion of private purchases was likely a key driver behind this.

The *Energy Saving and New Energy Vehicle Industry Planning 2012-2020* (节能与新能源汽车产业发展规划) issued by the State Council in 2012 addressed this. It pushed the half-million target to 2015 and set a longer-term target of 5 million by 2020 (GOSC, 2012). While other policies of the same era extended a new wave of subsidies and tax extensions to public and private purchases of EVs across the country – which flooded private capital into the sector (Ou et al., 2017). Despite the inclusion of private purchase subsidies, top-down public procurement requirements remained the core of securing demand for EV's in China (Howell, Lee & Heal, 2014; Pelkonen, 2018). In 2014 the Chinese central government and many sub-national authorities required their annual procurement to be at least 30% electric by 2016 (Ge, 2018). In 2016 this target was raised

¹³ In 2010, part of these subsidies were extended to private purchases, but the focus remained on public procurement (Ou, Lin, Wu, Zheng, Lyu, Przesmitzki & He, 2017).

to 50% by 2021 with an order issued by the central government (Lu, 2018; SIPA CGEP, 2020). These policies were further supported by additional national and sub-national policies¹⁴. While this paper focuses on LDV EV's, it is difficult to access data reflecting their share in Chinese public fleets. Accordingly, the electric bus fleet in China functions as an alternative benchmark to illustrate this policies progress because this fleet is almost exclusively public, and these numbers are easily accessible. Buses had been eligible for subsidies since 2009, and by 2019 there were 421,000 electric buses in the PRC. This represented 17% of all buses within China and 99% of the global electric bus fleet¹⁵ (Eckhouse, 2019). Shenzhen, a city in southern China and home to BYD, is also the first city in the world to fully run-on electric buses (Keegan, 2018; Ralston, 2020).

Adjacent to efforts securing demand, China also issued extensive policies to structure a secure EV supply. Throughout the mid-2010s, the central government issued a wave of industry standards, guidelines, manufacturing tax breaks, and other incentives to send clear market signals to the private sector. This was followed up with more explicit regulations targeting ICE's. There was a succession of new vehicle emission standards clamping down specifically on diesel vehicles – which are currently some of the most stringent in the world (see Yang, He, Shao, Cui & Mao, 2021). Simultaneously the National Development and Reform Commission (NDRC) released new regulations in 2018 indicating that newly added manufacturing capacity for ICEs would be strictly controlled and that any new additions required EV productive capacity. This was strengthened with a mandate requiring manufacturers to produce a certain share of NEVs (Stauffer, 2020). The mandate began in 2019 and required 10% NEV production (ICCT, 2018). The targets climbed annually and will reach 25% by 2025 and 40% by 2030. This is roughly in line with the IEA's SDS projections that show China reaching 43% EV sales by 2030 (IEA, 2021). However, this target could also climb higher as China is one of the few major economies that have announced an ICE ban entering force in 2035 (Fleming, 2020).

The Chinese government also set an industrial policy to drive research and rapidly scale innovation based within China. Since the mid-2000's, it has invested multiple billions into hundreds of R&D projects, dozens of NEV platforms, the establishment of several national labs, and several thousand patent applications on EV related applications (Pelkonen, 2018). It is hard to quantify what this looks like, but two national champions are a good representation of the outcomes. Both BYD and CATL are among the seven¹⁶ global battery producers categorized as Tier 1 by Benchmark Mineral Intelligence (2021). This means that these companies can provide high volumes of high-quality batteries to specific qualifications for multinational OEMs. For

¹⁴ The central government has a history of curtailing the issuance of license plates to ICE models to control local air pollutants. In 2019 the NDRC stopped local governments from restricting similar controls for licences plates for EV's (Lambert, 2019).

¹⁵ In contrast, the EU had 2,250 electric buses while the US had 300 (Eckhouse, 2019).

¹⁶ As of May 2021, the seven companies considered to be Tier 1 by Benchmark Mineral Intelligence are BYD, CATL, Envision AESC, LG Energy Solution, Panasonic, Samsung, and SK Innovation. Two of these companies are based in China, three in South Korea, and two in Japan.

example, the two of them together produce 95% of the global supply of lithium iron phosphate batteries (Lu, 2021). CATL was founded explicitly for manufacturing advanced battery technologies in 2011, and by January to August 2020 they were supplying 25.8% of the global battery market (Palandrani, 2020). They are also lead on innovation and have announced plans to deliver a “million-mile” battery for cheaper than \$100 kWh by the end of 2021 (Bloomberg, 2020). In contrast, BYD is both a battery and an EV manufacturer. On the battery end, they held 6.2% of the global EV battery market share from January to August 2020 (Ibid) and roughly 6% of global EV production in 2020 (Kane, 2021a). Before explosive growth in European EV sales in 2020 BYD held roughly 10% of the global share (Kane, 2020).

These figures only reflect two companies, though, while there are multiple very successful battery ventures within China¹⁷. The cumulation placed 363 GWh of battery production capacity – or 72.5% of global capacity in 2020 – within Mainland China (Moores, 2021). This dominance is not projected to wane soon either. China is currently building a battery gigafactory roughly every week and is projected to retain 66.9% of global Li-ion production – or 2013.5 GWh of production capacity – by 2030 (Ibid). This dominance mirrors China’s position in the global supply chains for critical minerals – which includes lithium and other materials used in Li-ion batteries. While dominance over critical minerals is relevant to the discussion of batteries, it is discussed in more detail elsewhere in this series (see Raimondi et al., 2021). Regardless, the cumulation of these policies has ensured that EV’s and the batteries powering them have supply and demand that are both available and accessible.

3.1.4. Affordability & Acceptability of EV’s in China

The road to making EV’s affordable in China has been a long process driven almost exclusively by government policies. Although the first policy to address the costs of private ownership were extended to five cities¹⁸ through the *Ten Cities, Thousand Vehicles* program in 2010 their impact was relatively minimal. This changed in 2013 when generous private purchase subsidies were expanded across the country. The calculations were different based on vehicle type, range, and overall cost, but, in general, BEV’s with ranges over 250 Km were preferred and eligible for up to ¥ 60,000 (8000-8500€) in support. From 2013-2015 the support declined annually by about 5% of the initial value. The central government also required that the subsidy not cover over 60% of the total cost of the vehicle. Chart 2 from Ou et al. (2017) illustrates how this did not occur because there was more than just the central government’s support. As the chart shows, when generous local and regional subsidies were also applied consumers could receive well over ¥ 100,000 (13,800-14,000€) in support ¥ 128,000 (17,800€) in the highest case. Their assessment across the best-selling BEVs found that consumers received on average a 51.5% discount of the total MSRP

¹⁷ This includes Hefei Guoxuan, Tianjin Lishen Battery, AVIC Lithium Battery, Shenzhen Desai Battery, and Shenzhen Waterma Battery (Grepow, 2020).

¹⁸ The five cities were Changchun, Hangzhou, Hefei, Shanghai, and Shenzhen.

in 2015 – with the maximum being 68.6% coverage on the Geely Zhidou base model. However, the case was a bit different for PHEV models that saw a substantially lower – but still generous – range of subsidies.

Prices for ten best-selling PEVs (basic model) in China, 2015 (Ou et al, 2017)

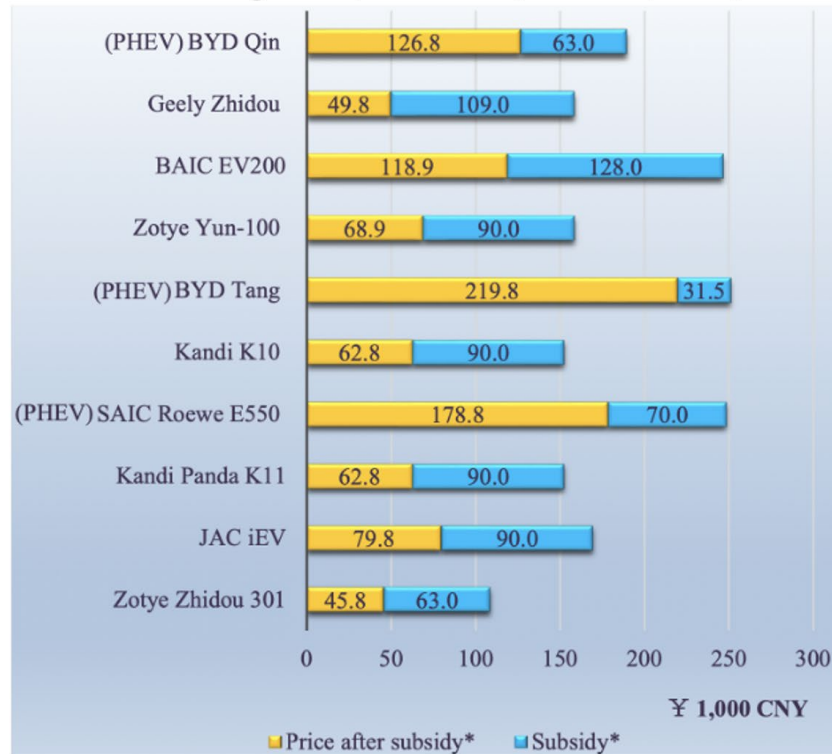


Chart 2 – Prices for ten best-selling PEVs (basic model) in China, 2015 (figure from the *Study of China’s Explosive Growth in the Plug-in Electric Vehicle Market* published through the Oak Ridge National Laboratory (Ou et al., 2017). Note - *represents the inclusive maximum value from local and central government subsidies.

Despite this substantial support, other policies included: tax reductions, rebates, or exemptions for purchasing EV’s (STA, 2012); the waiving or reduction of licensing and registration fees; rebates for home charging stations, and others (Ou et al., 2017). The cumulation of these often-overlapping policies rapidly brought down the cost of EV ownership extremely low. This was then leveraged against the scale of China’s internal market to spur enormous demand for cheap, mass-produced EVs. Chinese businesses responded and rapidly scaled up a domestic EV supply chain. Their core business model was to deliver massive volumes of affordable EVs that were small enough to navigate through China’s densely populated urban areas. Chinese entrepreneurs focused their research and development in this area and produced remarkable results. The average cost of EVs in China declined from 41,800€ in 2011 to 22,100€ in 2021 – otherwise a 47% decline in cost (JATO Dynamics, 2021). The price of 22,100€ was even 1,700€ lower than the average cost of ICE models sold in China for the same year (Ibid). This price decline has been seen across virtually all models; however, the smaller city cars are exceptionally inexpensive and popular. These models made up 40% of Chinese EV sales from January to May 2021, and they had an average price of 6,700€ – with the cheapest model available being roughly 3,700€ (Ibid). The average cost range and a new baseline model below 4,000€ is an anomaly unique to China,

and their rate of uptake reaffirms the success of Chinese innovation in delivering cost reduction.

Regardless of this price decline, Chinese consumers remain sensitive to pricing, and they prefer a cheaper subsidized model over a higher quality one with less support (Ou et al., 2017). This is reflected in sales data showing that 91% of EV's sold in China in 2018 cost below 40,000€¹⁹ (Statista Research Department, 2020). The sensitivity to cost was also seen in late 2019 when EV sales in China declined for five consecutive months after the remaining EV subsidies were cut in half (Soat, 2019). This decline was further hit by Covid lockdowns that more than halved EV sales in January and February 2020 (Barrett, 2021). The resulting shock pushed Beijing to extend its subsidies – albeit at a further reduced rate – until 2022.

Prior to this shock, China was the largest EV market in terms of unit sales for over five consecutive years, and in 2020 China's EV sales reached 1.337 million EV's – of which 1.272 million were LDVs – and reached an EV stock of 4.5 million LDVs (IEA, 2021; Transport & Environment, 2021). While the covid crisis has dampened growth, sales still grew by 8% from 2019 and represented 6.3% of the total LDV sales in China for in 2020 (Kane, 2021b). This growth has continued to rebound in 2021, with EV sales representing 20% of total LDV sales in China – reaching close to 2 million by September²⁰ (Kane, 2021c). At this rate, Chinese EV sales might reach 3.0 million in 2021 – which would represent half of annual global sales (Ibid). This occurs even as the subsidies are being further reduced, which illustrates that EV's are becoming increasingly affordable and acceptable without government support.

However, an interesting caveat of the subsidy extension was a price cap of ¥ 300,000 (+/- 40,000€) (Randall, 2020). This cap reflects the 2018 sales data and identifies that the cap is intended to support wider uptake. Yet, it also favours domestically sourced EVs that are often considerably cheaper than imported foreign vehicles. As Ou et al. (2017) found, domestic producers dominated the low-end segment of the Chinese EV market – whereas foreign firms dominated high-end sales. With this cap in place, foreign automakers will be hard-pressed to cut costs without relocating or sourcing major EV production to China²¹. This is what happened in 2019 when Tesla opened a gigafactory in Shanghai. Pressed with the obligation of lowering unit prices while keeping the ranges high, Tesla partnered with CATL to source domestically produced lithium iron phosphate batteries for its Shanghai made Model 3s (Randall, 2020). This preference was made over the traditional LG Chem batteries found in units produced in within the US, and the cost reduction eventually led Tesla to announce that it would use CATL batteries for all its

¹⁹ Inclusive of 24% of EV sales that were below 20,000€ and the 67% of EV sales that were between 20,000-40,000€.

²⁰ September 2021 was an exceptional month, with some 355,000 new EVs registered. The year over year growth rate at this point exceeds 170% (Kane, 2021c).

²¹ While this paper does not address this issue, it remains a geopolitically charged subject – especially regarding the forced transfer of technology and intellectual property.

standard Model 3 and Model Ys (Randall, 2020; Lu, 2021).

The notion that Chinese EV producers operate in the low-end market contrasts with Tesla setting up in China to produce globally exported models with CATL batteries over LG Chem cells. However, this juxtaposition highlights a crucial part in the next era of Chinese EV strategy – the global promotion of Chinese brands becoming synonymous with quality. The *New Energy Automobile Industry Development Plan for 2021-2035* (新能源汽车产业发展规划) (State Council, 2020) mentions this, while the *Made in China 2025* is almost entirely based on this – albeit for more than just EVs. It is a significant step in global acceptability that a world-leading firm like Tesla legitimates the quality of a Chinese produced battery through its global exports because it shows that they meet, or exceed, global competition.

This confirmation coincides with the new NEV plan that shows China building stringent supervision structures to enforce robust quality controls and standards on all domestically built EVs through 2035. If China can succeed at improving standards and quality oversight, it can then be leveraged to the international objectives in their plan, which is to integrate Chinese standards as a core element of international rules on EVs. Adjacent to improving standards, China's new plan also heavily emphasizes innovation through a series of technology breakthroughs in automation, battery recycling, cost reductions, and vehicle to grid integration (Ibid). The conjunction of leadership on quality standards, international rules, and innovation would be the platform allowing China to achieve its goal of becoming a powerful automotive country²².

3.2 The European Union

3.2.1. *The European Union's traditional approach to energy security*

Europe has a decade long history of relying heavily on energy imports. It was one of the first areas to industrialize and has sustained high energy demand for well over a century. Yet, despite abundant coal on the continent, most countries have very little or no domestic oil or gas production. Relying heavily on imports was shown to be a vulnerability during the first oil price shock in 1973 when Middle Eastern suppliers embargoed oil exports to American allies who supported Israel (Office of the Historian, n.d.). The resulting price spike set the tone for Western Europe to adopt a security of supply mindset that translated into support for energy conservation and the diversification of energy portfolios. Decades of this implicit mentality are visible in the EU's success with renewables, their substantial nuclear fleet, and the relatively low energy consumption per capita compared to North America.

²² The first sentence of China's NEV plan for 2021-2035 highlights that the development of NEVs is the core means for China to move from being a large-scale automotive country to a powerful one (《新能源汽车产业发展规划》是我国从汽车大国迈向汽车强国的必由之路) (State Council, 2020).

While this mentality gradually receded after the Cold War, recent security of supply concerns has revitalized its urgency. Russia's gas supply interruptions through Ukraine in the 2000s and the 2014 annexation of Crimea are considered particularly problematic. The gas interruptions of January 2006 and again in January 2009 impacted some smaller Eastern/Central EU Member States that were up to 100% reliant on Russia for gas imports. This pushed the EU to build a collective *Energy Security Strategy* (COM/2014/330) that ultimately led the European Commission (EC) to launch the *Energy Union Strategy*. This strategy aims to create an integrated and interconnected energy market that will reduce energy security threats by spreading vulnerabilities across the entire bloc.

As a macro unit, the EU had an import dependency of 61% in 2019, which is five points higher than the 2000 figure (Eurostat, n.d.). This average is high, but it hides the Member States over 90% dependent and others that are almost energy independent²³. However, it must be noted that the energy dependency indicator that measures imports over demand, though widely used, is not an adequate indicator for security of supply. Energy security of supply can be easily fortified through diversification and other resilience mechanisms. The EU energy union aims to address security of supply by increasing resilience to energy security and by reducing collective vulnerability to imports. This requires a functioning internal market that can leverage solidarity between Member States.

There is consensus that deep decarbonization is an ideal pathway to address both security of supply issues and fighting against climate change. High renewable deployment and energy efficiency gains ultimately eliminate most energy imports. However, the high penetration of non-dispatchable renewables creates other internal security of supply issues. These can be largely eliminated thanks to the development and availability of large-scale electricity storage. Batteries play an essential role in this. While decarbonization does thus have environmental components involved in this outlook, a significant motivator is also about securing an industrial competitive edge and energy supplies that are viable in the long term.

3.2.2. The role of batteries in decarbonizing the European Union and its self-sufficiency strategy to access batteries

The EU was a first mover on decarbonization, and their early policies delivered significant emissions cuts from the power sector. However, a 55% emission reduction from 1990 levels by 2030 (as set out in the 2021 "Fit-for-55" package proposed by the EC) represents a new challenge and needs to be addressed by all energy sectors. Large scale batteries can help the EU unlock deep emission cuts – especially in transportation, a sector that remains problematic for the bloc. In 2019, it was the second-largest source of EU emissions representing roughly 835 Mt CO_{2e} or 21.5% of

²³ In 2019, Member States such as Malta, Luxembourg, and Cyprus imported over 90% of all their energy resources, whereas Estonia imported less than 5% (Eurostat, n.d.).

the total (EEA, 2021). While this dropped to third place in 2020 because transport saw 12.7% emissions cut from COVID closures, this downturn will recover. This is because petroleum products remain the dominant fuel for transport, despite boosting the sector's share of renewable energy from 2% in 2005 to 10% by 2020 through the *Renewable Energy Directive* (Directive 2009/28).

Nevertheless, transport emissions need to be curbed because it is the only sector in the EU that has continued emission growth. Since 1990, transportation has grown by 24%, from 672 MtCO_{2e} in 1990 to 835 MtCO_{2e} in 2019, while most other sectors have declined (Eurostat, 2021). Accordingly, it is evident why battery-powered vehicles are central to decarbonizing transport, as the EU needs to reverse this upward trend before reducing emissions.

For the past few years, the EU has taken steps to build a path towards self-sufficiency in this domain. In the late 2010s, the Juncker Commission realized how import-dependent the EU was on key components for EVs. In response, the Commission began shaping an EU's industrial policy to reduce the blocs' import dependence on Li-ion batteries while securing the competitive edge in manufacturing. The Von der Leyen Commission has since carried this forward with a new wave of EU-level actions and initiatives. The combination of these efforts forms a solid push to build European self-sufficiency over battery production and EV manufacturing.

3.2.3. Availability & Accessibility of EVs in the European Union

Early on the EU recognized that public procurement could be a strong means to secure demand for clean vehicles. The two primary tools structuring this are the *Green Public Procurement* (GPP) standards and the *Clean Vehicle Directive* (CVD). EU-wide GPPs were first issued in 2008 (see COM/2008/0400), and the guidelines on transport have been repeatedly revised, most recently in October 2021 (Quintero & Garrido, 2021). These guidelines outline how several categories of procured services and vehicles can qualify, and they remain voluntary. In contrast, the CVD is obligatory for the Member States to follow. The CVD was first enacted in 2009 and revised in 2019. The initial directive set the framework for procurements to consider the lifetime environmental impacts of contracts. The updated CVD tightened this and introduced binding minimum procurement targets for clean LDV's, buses, and trucks from 2021-2030 (Directive 2019/1161). To qualify as a clean LDV requires an average of 50 gCO₂/km between 2021-2025 and after 2026 this lowers to 0 gCO₂/km. The targets range between 17.6-38.5% for LDVs, but the majority of the bloc uses the target of a 38.5% reduction from 2020 levels by 2030. While it is difficult to find data representing the effectiveness of these policies,²⁴ the combination of mandatory floors and robust guidelines create a high level of certainty in EV procurement for Member State governments and private actors.

²⁴ One study found that by 2012 55% of public procurement in the EU was using the CPP standards for transport (Renda et al., 2012).

The EU has created more demand for EVs by structuring emission regulations that place downward pressure on ICEs. As early as 2009, the EU set mandatory emission standards-setting 130 g_{CO2}/km as a combined fleet average for all vehicles sold in Europe by 2015 (Regulation 443/2009). This was followed up by a new agreement from 2019 that lowered the standards to 95 g_{CO2}/km for new passenger cars starting in 2020 (Regulation 2019/631). This measure forces automakers to either continue improving the efficiency of ICE models or to sell more non-emitting models (it is important to remember that these figures refer to tailpipe emissions only so that EVs have no emissions). Improving efficiency was viable with the first round, as automakers reduced the average by almost 22 g_{CO2}/km from 2010 to 2016 (EEA, 2020). However, this reversed after 2017, and emissions rose back to 122.4 g_{CO2}/km in late 2019 (Ibid). This is partly from automakers plateauing with efficiency improvements, while another key driver is higher SUV sales. Either way, the high fleet average has obliged automakers to sell more EVs to comply with targets. So far, this has been incredibly effective, as European EV sales skyrocketed after the new emission standards came into force in 2020 (Wappelhorst, Hall, Nicholas & Lutsey, 2020).

The pressure through emission regulations will continue to increase. These targets are scheduled for a further reduction from 2021 levels of 15% in 2025 and a 37.5% reduction after 2030 (EC, 2021a)²⁵. They were also included in the updated nationally determined contributions (NDCs) submitted to the UNFCCC on behalf of the EU (EU2020, 2020). The updated NDC indicates that they are open targets – which means that they are subject to a mandated review in 2022, where they can be revised upwards. A recent proposal from the EC is considering raising the 2030 target from 37.5% to 55% and adding a 100% reduction target by 2035 (Carey & Steitz, 2021). While a 100% reduction is not explicitly an ICE ban, it functions like one. Nevertheless, this provision remains to be negotiated between the Member States. However, eight of them already have ICE ban dates ranging from 2030-2040, while many others have similar proposals circulating. Several municipalities across the EU have adopted local bans targeting diesel vehicles (see Bernard, Hall & Lutsey, 2021). The signals being communicated by European legislators is quite clear that these rules will continuously tighten and that automakers will need to offer EVs if they want to continue supplying vehicles to European markets.

Consistent and clear market signals working in conjunction with multiple policy levers give the EU both the security of supply and demand of EVs going forward. The EU appears to be well on track to reach the EC's target of 30 million ZEV's operating within the EU by 2030 (EC, 2021b). The IEA (2021d) projects that such targets will keep Europe as either the biggest – or behind China as the second biggest – EV market in the world through 2030. With annual EV sales reaching 7.1

²⁵ This legislation also rewards the early movers with a super-credit system for low emission vehicles produced between 2020-2022. Additionally, it also makes provisions to relax the specific emission targets of manufacturers that produce more than 15% low emission vehicles between 2025-2030 and 35% from 2030 onwards (EC, 2021a).

million under the SPS or 13.3 million in the SDS. The problem with this level of penetration is that the EU has historically been one of the weakest producers for Li-ion batteries. In 2018, the entire bloc accounted for less than 3% of global production (Tsiropoulos, Tarvydas & Lebedeva, 2018), making them almost entirely reliant on imports for EVs sold within the EU. This is a major concern for European policymakers who do not want to replicate Germany's experiences with the solar industry²⁶ or to trade gas for battery import dependency. Brussels would rather use decarbonization incentives to build a green industrial base within Europe – so that they have the strategic autonomy to control their energy transition without facing obstruction from external forces or building in a deeper import dependence for such a valuable good as batteries.

To address this gap, the EU has taken steps to spur a blocwide industrial policy to coordinate what they consider to be a strategically vital sector. In October 2017, the EC (2021d) launched the *European Battery Alliance* (EBA) and released a *Strategic Action Plan on Batteries* in May 2018 (COM/2018/293). The former serves as an industrial platform that centralizes stakeholders²⁷ across the entire European battery value chain to coordinate their efforts in developing an innovative, competitive, and sustainable battery supply chain that can meet the EU's future demand (EC, 2021c). In contrast, the strategic action plan sets a guiding framework with six targets²⁸ and the regulatory and non-regulatory measures the EU will take to reach them. The end goal of both is to centralize the blocs' individual efforts into a collective "***cross-border and integrated European approach covering the whole value chain of the batteries ecosystem***" (original emphasis in COM/2018/293, p. 1).

A key midterm goal guiding this is to have at least 15 gigafactories operating within Europe capable of supplying 360 GWh of batteries to 6 million EVs by 2025 (EC, 2021d). Thus far, the EU's efforts have increased the continent's share to roughly 5.4% of global capacity, or roughly 27 GWh of the 500 GWh, in 2020 (Moores, 2021). This upward trend will continue through to 2030 as waves of new factory announcements²⁹ continue to come forward. As of February 2021, Benchmark Mineral Intelligence (as cited in Moores, 2021) projected that Europe's share of global production capacity could climb to 16.7% – over 500 GWh by 2030. Although others offer different

²⁶ Throughout the 2010s, the German government established an industrial strategy that subsidized broad solar deployment as an attempt to build out German solar panel production. The policy helped increase deployment, but German solar production failed because Chinese producers were heavily subsidized. This resulted in German subsidies helping deploy subsidized solar panels produced in China.

²⁷ The EBA connects EU national authorities, regional governments, industrial actors, and researcher centers active in the battery supply chain.

²⁸ The six targets include: securing access to raw materials for batteries; supporting investments into European battery cell manufacturing; strengthening industrial leadership through accelerated R&D; building out a skilled workforce across the value chain; supporting a sustainable EU battery cell industry; ensuring consistency with other strategic frameworks (COM/2018/293).

²⁹ By April 2021, there were well over 700 GWh of capacity in announced projects, although not all of them will continue through to development (Jacobs, 2021).

projections,³⁰ it can be generally expected that the investments being made so far will make Europe almost self-sufficient and the second largest battery producer (behind China) by 2025 (EC, 2021e). The EBA has already attracted well over 400 actors to invest 100€ billion (EC, 2021d) into 70 industrial projects across the entire European battery supply chain, and much of this has been de-risked by the European Investment Bank (EC, 2021e).

Nevertheless, it is not the EU's goal to supplant China as the dominant producer or become just self-sufficient. The real long-term aim is to establish industrial leadership over the sustainable and circular corner of the battery market. This will be done by improving clean innovation within the battery value chain and implementing environmental and ethical standards along the way. The EBA has played a central role in coordinating blocwide investments into the former. Although there are many mechanisms for funding,³¹ the two *Important Project of Common European Interest* that the EC approved in 2019 & 2021 are good examples of blocwide cross-sectoral coordination. These petitions were launched by 12 Member States, and they provide 6.1€ billion in grants to projects throughout the battery value chain. The money granted is expected to leverage an additional 16€ billion in private capital (EC, 2019; EC, 2021f).

Adjacent to this, the EU is also pushing innovative regulations on circular batteries. On December 10th, 2020, the EC proposed a revision (COM/2020/798) to the *European Batteries Directive* (European Parliament, 2021). The proposal aims to regulate unsustainable aspects of the battery value chain by setting targets for recycled content and issuing standards for lifecycle emissions and other ethical requirements. This will be reinforced by comprehensive labelling and a 'passport' system allowing batteries and their content to be traced through the supply chain (Halleux, 2021). Fostering transparency and enforceable high standards is a way to rebalance the global market so that all participants are competing under the same rules. This is a way to push back against bulk producers with a competitive advantage of manufacturing in an area with weaker regulations.

3.2.4. Affordability & Acceptability of EV's in The European Union

The European Union has a robust and competitive EV market where sales have continuously grown over the past decade. Yet, 2020 was an exceptional year with many milestones. After years of price decline, EV's became cost-competitive with ICEs on the total cost of ownership for more than half of the EU's auto market (Bernard, Bieker, Pettigrew, Schultz, Smorodin, Wappelhorst, 2020). This was partly due to the continued declining prices of Li-ion EV battery packs that fell to 115€/kWh in 2020 – an 89% reduction in real terms since 2010 (COM/2021/952).

³⁰ Other projections vary; BloombergNEF projects that Europe's share of global production could reach as high as 31% by 2030 (as cited in Jacobs, 2021).

³¹ Some other financial instruments include the Next Generation EU, Horizon Europe, Cohesion Funds, Innovation Funds, or other Member State recovery efforts.

With the costs getting more competitive and newer emissions legislation restricting ICEs, European consumers were more incentivized to buy EV's in 2020 than before. From 2019 to 2020, there was a record 146% increase in EV sales across Europe³² – reaching 1.365 million sales (Bernard, Hall & Lutsey, 2021). The EU-27 accounted for 1.046 million of these EV sales and had an even higher relative growth rate of 170% for 2020 compared to 2019 (Transport & Environment, 2021). Overall, this surge in sales represented 10.5% in total car sales compared to slightly below 3% in 2019 (COM/2021/952). The substantive growth in relative terms was partly because net growth in EV sales and a 20% decline in total LDV sales in 2020. Nevertheless, the market trend is undeniable as Europe's EV sales for 2021 were already 1.58 million units by September – otherwise already 200,000 above the previous year's record total (Kane, 2021d). The cumulation of these sales helped Europe³³ overtake China to become the largest market for EV's (IEA, 2021) – accounting for almost a third of the global stock³⁴ with over 3.2 million EVs.³⁵

Despite this substantial success, there is significant disparity behind these macro figures. Some Member States, like Sweden, have over 30% EV sales, whereas others, like Cyprus, have less than 1% (COM/2021/952). This disparity occurs at the policy level as well. Some of the wealthier Member States, like France or Germany, have substantial policy incentives – including over 9,000€ in purchase incentives and tax reductions³⁶ (ACEA, 2021a). Depending on the models MSRP and which Member States policies we consider, this can reduce the purchase cost by 20-40% or more³⁷. In contrast, some Member States with lower GDP, like Poland or Cyprus, have minor policy support or none, like Estonia. The work of ACEA (2021b) finds a correlation between GDPs per capita and the general uptake of EVs – which they argue is a primary reason why affordability remains a barrier to EU consumers. Although this is generally true, some Member States with lower GDP and low EV deployment have generous policy support to help push EV's on the roads - i.e., Romania (ACEA, 2021a; ACEA, 2021b).

Figure 1 illustrates the EV deployment gap across Europe and shows which countries were the first to develop robust markets. Policy innovators like the Netherlands and Norway have led the way in designing policies to make EVs affordable for well over a decade³⁸. Countries like France and Germany were early followers of this trend and have been more recently joined by the likes

³² In this context, Europe includes the EU-27, the United Kingdom (UK) and members of the European Free Trade Association (EFTA) (Iceland, Norway, Liechtenstein, and Switzerland).

³³ Inclusive of the EU-27, the UK and members of the EFTA.

³⁴ According to the IEA (2021d), the global stock of battery electric and plug-in hybrid LDVs in 2020 was 10.1 million.

³⁵ A combination of 1.8 million BEV's and 1.4 million PHEV's (IEA, 2021).

³⁶ In the case of France, this can provide up to 19,000€ in cost savings for purchasing an EV. President Macron has assigned 1.3€ of France's recovery package to fund this (JATO Dynamics, 2021).

³⁷ Assuming for an MSRP range between 20,000€ to 50,000€.

³⁸ In 2020 Norway had a BEV and PHEV sales share of 76% while the Netherlands had 25% (BloombergNEF, 2021).

of Spain and Italy. This grouping is significant – especially France, Germany, Spain, and Italy – because they represent the economic and demographic majority of the bloc and are also the largest markets for new LDVs in the EU³⁹. The fact that the four of them have already reached lifetime cost convergence is a significant indication of where the EU’s EV market will continue going forward (Bernard, Bieker, Pettigrew, Schultz, Smorodin, Wappelhorst, 2020). As they propel forward, the Eastern portion of the EU will likely continue to face problems with affordability because policy incentives remain weak; new vehicle sales also remain low⁴⁰; and GDP per capita is lower. This disparity reflects that the EU as a geo-economic bloc struggles because there are no EU-wide support mechanisms for EVs that can make deployment symmetrical. As a result, the EU might require some application of cohesion funding to increase EV penetration in all corners of the bloc.

³⁹ Adoption rates in Western Europe were generally above the 10% share in sales in 2020, whereas the Southern European Member States were 4% for Italy and 5% for Spain. The notable improvement for the South is that these figures quadrupled from the single percent figure in 2019 (BloombergNEF, 2021).

⁴⁰ According to BloombergNEF (2021), the Eastern Member States account for roughly 10% of all new vehicles sold in Europe.

Despite national disparities, the momentum of EV adoption in the EU is undeniable. As

Maturity of EV markets in Europe by country (BloombergNEF, 2021)



Figure 1 – Maturity of EV markets in Europe by country (Map based on data from BloombergNEF, 2021).

affordability comes closer to parity, the uptake will rely more on the acceptability of EVs⁴¹. The addition of new models is a crucial factor spurring further adoption. European automakers have picked up on this and rapidly expanded their EV lineups across the EU (see Bernard, Hall & Lutsey, 2021). Thus far, for 2021, major European automakers appear to be the most accepted brands across the bloc. By September 2021, Volkswagen Group, Stellantis, Daimler, and BMW Group had a combined 58% market share of the EU's EV market while holding six of the ten top models (Kane, 2021d). Some Korean models were also quite successful. Nevertheless, with 100,993 units sold in Europe by September – the American made Tesla Model S remains the most popular model by almost double their nearest competitor – the Volkswagen ID.3 with 53,037 (Ibid). The combination of these figures illustrates that Europeans do support locally made brands, but there is also a high level of acceptance for foreign brands.

3.3. The United States of America

3.3.1. America's traditional approach to energy security

⁴¹ Although not within the scope of this analysis, this will inherently converge to the problems associated with range anxiety and the deployment of EV charging infrastructure. The work of Falchetta & Noussan (2021) shows how the latter persists to be a problem across the EU, that creates new inequalities between urban and rural communities.

In contrast to the PRC and the EU, the US has abundant energy resources and has a history of exporting them globally. It was not until after WWII that America became an energy importer because domestic oil consumption soared with the mass adoption of personal automobiles (CFR, 2021). As consumption rose, import quotas checked imports that helped spur domestic production. Yet, domestic supply could not keep up, and the quotas were lifted in mid-1973 to avoid a gasoline shortage. This did little as the oil embargo sent prices skyrocketing months later. The price shock rattled the American economy, and the government responded by adopting a security of supply mindset that has since revolved around ensuring stable energy prices. While there has been some policy evolution, the centrality of price – or affordability – is still circulating within the national psyche. Everyday citizens remain extremely sensitive to energy prices.

Prioritizing prices places international trade at the core of American energy security as functioning global markets ensure that competition drives innovations that lead to cost reduction (Burlinghaus & Gordon, 2020; Goldwyn, 2020). In this scope, American energy independence is not desirable because it would not, and could not, provide energy security (American Security Project, 2021). Not only does foreign competition help keep domestic costs from rising, but it also allows for the US to import specific resources while also allowing them to export their own. This dual nature is seen in America's relationship with Canada and Mexico. Not only are these countries the largest destinations for American energy exports⁴² (see AGI, 2021), but they are also the largest source of energy imports to the US⁴³. These mutually dependent relationships link both the security of American energy supplies and the security of demand for American energy products to its neighbours (Goldwyn, 2020). Former Brigadier General Stephen Cheney and Andrew Holland (2017) call the free trade of energy between neighbouring allies “shared security” – which to them is the only true form of American energy security.

The emphasis on affordability contrasts with Europe's focus on energy conservation because strong production within North America makes energy more available and accessible to the US. However, because North American prices are heavily reliant on global commodity prices, the US has historically used foreign policy to stabilize global energy markets to ensure that energy imports remained affordable and uninterrupted. Military cooperation with major producers in the Middle East or Naval support to ensure freedom of navigation through arterial points illustrate this. However, the recent shale revolution has made America a net energy exporter.

⁴² In 2020, the US imported over 240mb of Mexico's heavy crude and exported over 1mbd of refined petroleum products to Mexico. Mexico is the top foreign purchaser of American refined products as over 70% of their diesel, natural gas, gasoline, and jet fuel come from the US (International Trade Administration, 2021). In 2018 70% of all Canadian energy imports came from the US – this represented CAD 35.5 billion in value (NRC, 2019).

⁴³ Canada is the largest foreign energy supplier to the US, which imports refined Uranium, oil, natural gas, and power (Goldwyn, 2020). In 2018 the 1/5th of US oil consumption came from Canada, and the US represented 89% of all Canada's total energy exports – including 95% of its oil exports (NRC, 2019). In 2020 Canada sold 67 TWh of power to the United States – much of this was either hydro or nuclear power from Quebec and Ontario (Cahill, 2021). These low carbon power imports are critical for border states decarbonization strategies (i.e. New York State).

While this change does insulate America from some price volatility, it does not make them energy independent (Burlinghaus & Gordon, 2020). If anything, such a change has adjusted the American vision of energy security from focusing only on imports to one that also actively facilitates exports (Ibid). This compounds the importance of open trade to American energy security, because the security of both supply and demand become imperative to ensuring national and regional energy security

3.3.2. The role of batteries in decarbonization and self-sufficiency strategy to access batteries

While decarbonizing America will require batteries in various applications, their usage in transportation is particularly crucial. Transport is the largest share of emissions in the US, and it accounted for 29% or 1.9 Bn t CO₂e of the total 6.558 Bn t CO₂e emitted by the US in 2019 (EPA, n.d.). Roughly 82% of this came from LDVs and medium and heavy-duty trucks, at 58% and 24%, respectively (EPA, 2021). Other than the downward pressure resulting from economic crises in 2008 and 2020, this sector has shown persistent growth since the early 1990s (Statista, 2021). Emissions for this sector remain substantial because over 93% of all the energy used came from fossils in 2020 (EIA, 2021b). These metrics indicate that the rapid electrification of transport is crucial if the US wants to reach their 2030 NDC of 50-52% emission reduction from their 2005 levels.

The Biden administration recognizes these trends and centralized the electrification of transportation in their “*Build Back Better*” agenda. Not only will this reduce American emissions, but it will also reinvent American automotive manufacturing, rebuild the underlying core of American infrastructure, and create significant employment for Americans. To capitalize on this, President Biden is mobilizing a “*whole of government approach*” to spur the buildout of a domestic EV and Li-ion battery industry to fuel it. After one month in office, he signed Executive Order 14017, which triggered two things (The White House, 2021a). First, an immediate 100-day supply chain review to assess vulnerabilities and means of improving resilience for four key products, which included advanced batteries. Second, a one-year review to develop a strategy on how to rebuild the industrial base within the US for six sectors – including energy and transportation.

Their inclusion highlights the strategic priority for the Biden administration, and with the 100-day review completed and the launch of the American ‘*National Blueprint for Lithium Batteries*,’ there are signs as to how the US will proceed. The 100-day review flags numerous critical gaps within the American battery supply chain (The White House, 2021b), while the blueprint candidly acknowledges that the US is behind both China and the EU in developing a national battery strategy. In recognition of these issues, the blueprint delivers a vision that “*By 2030, the United States and its partners will establish a secure battery materials and technology supply chain that supports long-term U.S. economic competitiveness and equitable job creation, enables decarbonization, advances social justice, and meets national security requirements.*” (FCAB, 2021, p. 5).

3.3.3. Availability & Accessibility of EVs in the United States

The prospects of President Biden building a strong American EV sector are good, as the US spent decades trying to build both an industry and a stable market. The first major policies were passed through the *Energy Independence and Security Act* of 2007 and the *Energy Improvement and Extension Act* signed by President Bush in 2008. The former required manufacturers to improve their average fuel emission by 40% by 2020, and the latter created a tax credit of \$2500-7500 (2200-6600€) in tax refunds for EV purchases (IRS, 2021). These bills were followed by the Obama administration that took office amid the Global Financial Crisis. Like President Biden, they viewed building an EV industry as a vehicle of economic revival. Capitalizing on the tax credit, President Obama signed an Executive Order targeting 1 million EV's in American by 2015. This was backed by targets to increase EVs in public procurement (Exec. Order No. 13514, 2009), a \$2.4 billion (2.1€ billion) appropriation in the *American Recovery and Reinvestment Act* of 2009, \$8.4 billion (7.4€ billion) secured through the DOE's *Advanced Technology Vehicles Manufacturing Loan Program* and strengthening of the *Corporate Average Fuel Economy* (CAFE) standards⁴⁴.

The combination of these policies yielded mixed results. In contrast to the credit's success, federal procurement has consistently failed to secure demand for EVs. Of the 358,078 total vehicles purchased by the federal government from 2009-2015, only 24,816 - or 7% - were low emission vehicles (Government Fleet, 2015a). It is also suspected that the substantive majority were hybrid EV's rather than EVs (Government Fleet, 2015b). After this failure, Obama issued a new Executive Order scrapping the targets from 2009 and mandating agencies to lower their fleetwide emissions by 30% from 2014 levels by 2025 and increase their share of ZEVs in procurement to 50% by 2025 (The White House, 2015). Adjacent to this, President Obama also launched a wide range of projects through sub-national governments (The White House, 2016). During the Trump administration, these targets were not adhered to. However, when President Biden took office, he issued a new Executive Order on *Tackling the Climate Crisis at Home and Abroad* that accelerated the targets towards complete electric procurement (The White House, 2021c). This was followed up by a new Executive Order issued on December 08, 2021, setting the goal to have 100% ZEVs in new federal procurement by 2035 and 100% LDV acquisition by 2027 (The White House, 2021d).

While these new targets are a good development, there is a severe gap in credibility because, in 2021, less than 1% of the 657,000 vehicles in the American federal fleet were electric (Skibell, 2021). Because even if the vehicle lifetime costs are lower, Congress still needs to legislate an increase in federal procurement budgets before EV uptake can be possible. The bipartisan gridlock within American federal politics will continue to make securing demand through public procurement a

⁴⁴ The stronger CAFÉ standards came into force in 2012 and included a credit system that incentivized automakers to produce more BEV and PHEV models.

problematic task. Even though the Biden administration is supported by a Democratic majority in both chambers of Congress, efforts to legislate funding for EV procurement is an uphill battle. The Bipartisan Infrastructure Law from late 2021 appropriated \$5 billion (4.4€ billion) to deploy electric school buses federally; yet, most of the Biden administrations requested EV funding was dropped in this legislation (The White House, 2021e). The ongoing Reconciliation Bill may provide more funding for procurement. An analysis from November 2021 showed roughly \$9 billion (7.9€ billion) appropriated federal procurement targeting EVs (EV Hub, 2021). Nevertheless, the continued integrity of these bills remains in question as federal policies have backtracked in the past. In the absence of federal leadership, States and municipalities have had significant success in using their public procurement to secure demand within their jurisdictions. As discussed elsewhere in this series (see Lu et al., 2021), California remains an example of policy leadership in the US. For over the past decade, they have mandated the adoption of ZEV's - the most recent of which targeted 50% ZEV procurement by 2025 (State of California, 2021).

These policies also had mixed results securing EV supply. The Bush-era's CAFE standards were intended to improve vehicle efficiency and reduce oil imports. Under Obama, this was adjusted to incentivize automakers to produce EVs. His administration strengthened the annual efficiency gains to 5% and raised the efficiency target to 55 MPG by 2025. This was paired with a credit system that rewarded EV production within the US (The White House, 2012). Studies show that these policies effectively accelerated EV market penetration (see Sen, Noori & Tatari, 2017). However, the standards were weakened by the Trump administration. However, the Biden administration will review this and likely strengthen the annual adjustment to 8% for models produced in 2024-24 (NHSTA, 2021). Despite the repeal, major auto companies protested this slowing down electrification. Ford even reaffirmed their commitment to California's higher standards⁴⁵ because it provided regulatory stability and reduced emissions (Eisenstein, 2019; Shepardson, 2020).

Beyond these policies, there was also a significant investment into the US industrial base. The major investments were \$2.4 billion (2.1€ billion) in grants through the DOE for *Supporting Next Generation Electric Vehicles* production in the US,⁴⁶ and the activation of \$8.4 of the \$25 billion (7.4€ of 22€ billion) available to the DOE's *Advanced Technology Vehicles Manufacturing* (ATVM) loan guarantee program. The majority of this was invested in innovation or equipping American manufacturers to produce EVs (CRS, 2015). The best example is Tesla and its \$465 million (410.4€ million) loan guarantee from the ATVM (LPO, 2017). This loan was given in 2010 to cover the costs of launching production of the Model S. The Model S launched in 2012, and by 2015 they

⁴⁵ As the Trump administration repealed emission standards, the State of California reached an agreement with several major automakers for them to continue abiding by the previously set clean vehicle standards (State of California, 2019).

⁴⁶ This included: \$1.5 billion in grants to US based battery producers; \$500 million in grants to US based producers of EV components; and \$400 million in grants for demonstration and proof of concept infrastructure projects (DOE, 2009).

had taken over a quarter of the American EV market (AFDC, 2020) while also becoming the most sold model in the world in that year (EV Volumes, n.d.). The continued success of Tesla⁴⁷ shows how American investment into private innovation can translate into a strong domestic EV supply.

President Biden appears determined to build on the successes and correct the failures with the new target for half of all LDV sales in the US would be EV by 2030 (The White House, 2021f). While this goal is possible, America's current battery production is not enough. The US has managed to maintain self-sufficiency, as 69.6% of all EV battery cells and 87.2% of all EV battery packs used in the US were produced domestically in 2020 (Zhou, Gohlke, Rush, Kelly, Dai, 2021). However, the logistics of supplying batteries for its current 300,000 annual EV sales is considerably different from the projected 8.1 million annual sales in 2030 if EV's account for half of all sales (IEA, 2021)⁴⁸. American Li-ion battery production capacity was only 9.2% - or 46 GWh of 500 GWh - total global capacity in 2020 (Moore, 2021). While new additions could fill this gap, the announcements made by February 2021 would only put the US at 11.9% - or 358 GWh of the 3,009.7 GWh - of global capacity by 2030 (Ibid).

The primary reason for this gap is that there is no leading Li-ion battery company outside the Asia Pacific. All leading companies are from China, Japan, or South Korea. Moreover, most American auto companies, except Tesla, have been unwilling to invest in battery cell production - preferring to rely on suppliers (Wayland, 2021). However, as the scale continues to climb, automakers will inevitably lean heavier into the industry - lest they rely on importing batteries produced in Asia for their vehicles. Under pre-pandemic circumstances this might have been viable. But when facing consistent supply disruptions and shortages for semi-conductors' automakers are increasingly willing to move towards vertical integration and regionalization of supply chains. Ford,⁴⁹ Stellantis,⁵⁰ and Toyota⁵¹ have all recently announced new partnerships with global battery leaders to establish new US based battery factories. These announcements overlap with the launching of Ultium Cells - a \$2.3 billion (2€ billion) joint venture launched by GM and LG Chem in early 2020 that aims to offer 30 GWh of battery production capacity for GM vehicles (GM, 2020). These new capacities run adjacent to other announcements that almost the

⁴⁷ In late 2021, Tesla became the first automaker in history to reach over \$1 trillion (880€ billion) in market capitalization (Mathews, 2021).

⁴⁸ The IEA (2021) Sustainable Development Scenario projects the US to reach 8.1 million EV sales annually by 2030. As a proportion of sales their projections are roughly in line with President Bidens 50% target.

⁴⁹ In September 2021, Ford, in partnership with SK Innovation, announced \$11.4 billion (10€ billion) of new investment into creating US based battery factories to start production by 2025 (Wayland, 2021).

⁵⁰ In October 2021, Stellantis announced a joint venture with LG Energy Solutions to add up to 40 GWh of battery production capacity to support its North American operations (Lewis, 2021).

⁵¹ In October 2021, Toyota indicated that by 2030 it would invest \$3.4 billion (3€ billion) into battery development and production facilities based in the US (Wayland, 2021).

entire US auto sector aims for 40-50% EV sales by 2030⁵² and that they will invest well over \$100 billion (88€ billion) into their US manufacturing to do this.

These announcements are substantial in their scale and frequency, which shows the overwhelming consensus that American private actors are willing to invest in securing EV supplies for American markets. In contrast, the discourse over the next generation of EV policies has been sluggish and fractured. The *National Blueprint for Lithium Batteries* indicates that a primary 2025 objective is to structure a comprehensive federal framework supporting EVs. However, with the Republican half of the American political system mostly rejecting supporting EV deployment (Gordon & Jackson, 2021) and the internal components of the Democratic half obstructing new policies to extract political concessions, this remains unlikely (Bloomberg & Laing, 2021). Deep polarisation is persistent and will continue to make any US strategy to secure EV demand or supply only partially effective. The executive branch and its agencies control powerful policy levers and have some discretionary resources at their disposal – such as the remaining \$17 billion (15€ billion) allocated to the DOE AVAT. The national blueprint mentions leveraging such funding to support innovative EV projects. Nevertheless, policy support for EV deployment will remain weak without congressionally appropriated funding. In the absence of this, the private sector has a crucial role in setting the bar and moving forward.

3.3.4. Affordability & Acceptability of EV's in The United States

The affordability of EVs has long been an issue in the US. The EV tax credit implemented by President Bush in 2008 was an attempt to address this by refunding between \$2500-7500 (2200-6600€) of the purchase price. This incentive was successful early on as it was seen to have raised EV sales by roughly 29% from 2010-2014 (Foy, 2019). However, the actual rebate is dependent on the relative cost of the make and model. The three most popular models in the US for 2013 were the Chevy Volt, Nissan Leaf, and Tesla Model S. A maximum rebate of \$7500 off these MSRPs⁵³ of these models would give an effective subsidy of 26% for the Nissan, 19% for the Chevy, and 12% for the Tesla. In any of these cases, the EV would remain between several thousand and ten thousand dollars higher than an equivalent base model ICE⁵⁴. Subnational policies did help fill this gap, and by mid-2021 45 states and the District of Columbia had some additional support (Hartman & Shields, 2021). California's *Clean Vehicle Rebate Project* remains one of the more generous examples, as consumers could be eligible for up to \$7,000 (6,180€) (CVRP, 2021).

Nevertheless, the tax credit was implemented in 2008, and it remains limited. The real value of

⁵² Major commitments to transition to EV production has been made by some of Americas most prominent auto companies including all three of Americas major auto companies – General Motors Company, Ford Motor Company, and Stellantis (Motavalli, 2021).

⁵³ The MSRP for a 2013 Nissan Leaf was \$28,800 (25,400€), while it was \$40,000 (35,200€) for the Chevy Volt and \$62,400 (55,000€) for the Tesla Model S.

⁵⁴ For example, a 2013 Nissan Sentra S base model was \$16,780 (14,800€) and the base model of a 2013 Chevy Cruze was \$18,000 (15,900€).

\$7500 in 2008 was significantly larger than it is now. Simultaneously the nominal price of vehicles has also increased. Even if the price gap between EVs and ICEs has shrunk, the incentive has still become weaker over time. At the same time, it only covers the first 200,000 sales of any given manufacturer before expiring (IRS, 2021). While this cap allows for less competitive or new EV brands to enter the market from an advantageous position, it also ends support for the makers and models that consumers are actually interested in purchasing. These problems arise because the credit is from 2008, and it was designed to help the US reach 1 million total EVs – not a 50% EV market share.

The credit expiration is problematic because EVs are not expected to reach cost parity in the US until the mid or late 2020s, and deep EV penetration will require continued support (Lutsey & Nicholas, 2019). At the same time, primarily domestic brands will be the ones disadvantaged. Tesla and GM surpassed this threshold in 2018, and both Ford and Toyota will likely pass it in 2022 (EVadoption, 2020). This is somewhat problematic because it would weaken the uptake of American made EVs as the sector begins to take off. President Biden has made efforts to raise the cap to 600,000 and increase the credit value by \$4,500 (3,970€) for domestically built vehicles linked to unionized labor. While prominent political actors find these acceptable, major domestic and international actors have regarded it as unacceptable. Republican politicians almost universally oppose these provisions, and critical Democrats – like Senator Manchin – have expressed hesitation on the link to union labor (Bloomberg & Laing, 2021). While crucial trading partners and allies – such as Canada, the EU, Japan, and South Korea – oppose such measures and lobby to block them (Lawder, 2021).

Despite the unacceptability, sustained credits are needed because American EV deployment remains low. Obama's target of 1 million EVs on the road by 2015 was half a million vehicles short. The target was only hit in 2018 because of the incredible popularity of Tesla made EVs. In 2018 Tesla launched their Model 3 and sold 139,782 units that year and 154,840 units in 2019 – this accounted for 38% and 47% of total annual EV sales in the US for each respective year (AFDC, 2020). In 2018 US EV sales grew by 81% from 2017. Roughly 70% of the 81% growth was caused by sales of Tesla's new Model 3 (Pyper, 2019). This remarkable growth translated into a market that was also very consolidated, as Tesla accounted for 79% of US EV sales in 2020 (Lambert, 2021). This consolidation is largely because US EV sales remain low. In 2020 they were only 306,000 of the 14.5 million LDV's sold in the US – roughly a 2.1% share (Gohlke & Zhou, 2021). Despite a 4% decline from 2019 EV sales, this is the highest relative share of total sales EV's have ever had because the total LDV sales declined substantially in 2020.

The prospects in 2021 are showing some positive developments. An analysis from Consumer Reports in late 2020 confirmed that for much of the American market, the lifetime cost of ownership for EVs had dropped below ICEs – which is a significant milestone to outright

purchase cost parity (Harto, 2020). There were also almost 300,000 new EV sales for the first eight months of 2021, which is slightly below the previous year's total (Kane, 2021e). This growth has been boosted by the new models made available and will be supported in the future by the enormous popularity of new SUV and truck models – like the F150 Lightning⁵⁵. However, Tesla remains the overwhelmingly preferred supplier with roughly two-thirds of the market share and a year-over-year sales rise of 79% (Kane, 2021e). This is peculiar because Tesla does not qualify for the tax credit, and even the most basic Model S and Model Y costs \$46,400 (41,000€) and \$57,990 (51,200€), respectively. This illustrates that the appreciation of a specific make or model is as equally important as pricing in the US EV.

4.0. Discussion Comparing China-EU-US

While China, the EU, and the US will lead the world on EV deployment and Li-ion battery production, there are fundamentally different dynamics that each actor will face to secure EVs for decarbonizing transport. On the macro level, the need to decarbonize transport varies. Although the US transport emissions are highest – its growth trend is similar to the EU's. In contrast, Chinese transport emissions are a relatively low portion of overall emissions. They are close to EU levels and less than half of the US despite having double the combined population of both. The contrast highlights that China is a developing economy, with a much smaller but rapidly increasing overall penetration of motorized private transportation. This infers that individual emission patterns in China are different than its peers. The EU and the US have emission-intensive transport habits, and these governments are working to decarbonize established transport networks. In comparison, China is still building transportation networks to connect the huge rural population while decarbonizing.

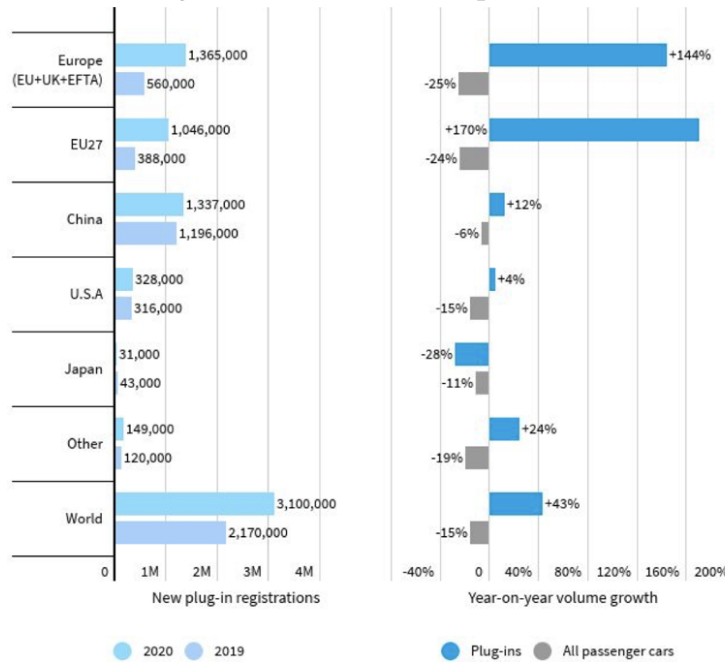
In terms of EV deployment, China had more EV's on the road than both the US and Europe combined. By 2020, China had an EV stock of 5.4 million while Europe had 3.3 million and the US had 1.8 million (IEA, 2021). This represented 4.5 million electric LDVs in China, 3.2 million in Europe (roughly 2 million in the EU-27) and 1.7 in the US (Ibid). It is reasonable for China to have a nominally higher EV stock because its auto market is larger than both the EU and the US⁵⁶. This is seen when comparing sales volumes from 2019 and 2020 and how they changed the actual share of total sales. Figure 2 helps illustrate this. It shows that in 2020, there were 1.365 million EVs sold in Europe (1.046 million of which were sold in the EU-27), 1.337 million sold in China, and 328,000 sold in the US (Transport & Environment, 2021). Europe as a continent had higher sales than China, but China still had almost equivalent sales to the EU and US together. However, EV sales in the EU skyrocketed in 2020 – growing by 170% from 2019. This growth put the EU's

⁵⁵ The new Ford F150 Lightning reached 200,000 pre-order requests by December 2021. At this point, the automaker has stopped accepting pre-orders as production might not be able to meet delivery for this volume of demand (Richard, 2021)

⁵⁶ According to the ACEA (2021c) China registered 21.16 million new passenger vehicles in 2019, while the EU registered 15.34 million and the US 13.91 million.

relative share of EV's to 10.5% - which is considerably higher than China's 6.8% or Americas 2.3% (Ibid). The higher relative share of sales in the EU indicates a much deeper penetration of EV sales.

EV volumes in major world markets (Transport & Environment, 2021)



Source: European volumes from ACEA quarterly AFV registrations. Global volumes from Statista. Other data from EV Volumes and best-selling-cars.com.

Figure 2 – EV volumes in major world markets (figure from Transport & Environment 2021 briefing titled *CO₂ targets propel Europe to 1st place in emobility race*).

Policies chosen by each respective actor has shaped the relative share of sales and total EV stock. All three actors view public procurement of EVs as a means to boost their share, and all three implemented procurement policies in the early 2010s. Each policy initially failed to get the intended traction, but the responses differed. China immediately strengthened incentives to push procurement even further in the early 2010s. This was advanced by aggressive procurement targets for 50% EV purchases by 2021. Several years later, the EU followed the revisions made to the Clean Vehicle Directive and more robust procurement standards. Nevertheless, the procurement targets of 38.5% by 2025 is much less ambitious than Chinas – and not even every Member State has it. The US did have more ambitious targets earlier than the EU, as Obama set a 50% EV procurement by 2025 target as early as 2015. However, the US has failed to reach any meaningful level of EV penetration in federal procurement because this process has been politicized, and policies have gone unfunded.

Adjacent to procurement policies, each actor used a mix of financial incentives. The US was the first mover to adopt a nationwide incentive for EV purchases. Nevertheless, this policy had extreme limitations. It was not overly generous, it did not cover public procurement, and it only covered the first 200,000 purchases from any given manufacturer. Because it has not been updated, it remains either too small or entirely inapplicable for most EVs currently sold in the

US. The Biden administration is attempting to address this by scaling up this incentive. Comparatively, the EU's incentives were also adopted early and have generally been more generous and broader than the US. They have also been successful in boosting deployment in different markets. However, there is no EU-wide policy consistency, making deployment extremely unequal between the Member States. The EU will likely need to deploy a series of new EU-wide incentives to strengthen cohesion and ensure that the gaps do not grow too wide. In contrast, China's subsidy was arguably the broadest and most generous. The coverage was national, it covered private purchases and public procurement, the incentives were very strong – especially relative to vehicle cost – and there were few exclusions until recently. China is the only actor of the three where incentives are being withdrawn – and despite this continues to exhibit strong growth.

While figures are hard to find, it is undoubtedly the case that this was extremely expensive. Nevertheless, China reached high deployment levels and is now refocusing its efforts by mandating the manufacturing sector with obligatory EV production targets. These mandates are unique to China, and both the EU and the US would likely not be able to implement such measures at a political level. The EU has taken a different approach to pushing deployment – by gradually strengthening regulations to push down on ICEs. The most recent change in regulation was in 2020, and it spurred a considerable jump in EV sales. The US has attempted to use similar policy tools as the EU through the CAFE standards. However, political adjustments have reduced the effectiveness of these policies. The US is peculiar in this case because their auto industry took the first step to pledge higher shares of EV manufacturing even when federal policies were being weakened.

Outside of policies, there is also considerable variation between consumer preferences for each market. Most Chinese consumers are foremost concerned about affordability, and they generally prefer cheaper models over premium quality (Ou et al., 2017). The local producers have picked up on this and targeted these consumers to offer them EVs at considerably lower prices than any other major supplier. This has given Chinese manufacturers a strong presence in the local market – except for the premium sales dominated by imports. The emphasis on affordability is representable in a JATO Dynamics (2021) report that found Chinese EV prices have declined by 47% in China since 2011. In contrast, the EU and US prices have increased by 28% and 38%, respectively (Ibid). This is reflected in terms of the average cost of EV sales. This is understandable for the US because most current EV sales are not defined by costs or parity with ICEs – rather by a brand's perceived prestige and quality (Ou et al., 2017). The majority of EV sales in the US are Tesla's – which are expensive and are also excluded from the existing incentives. The importance of costs will likely become more central as the US sales reach a deeper penetration. However, the US has a much higher GDP per capita than China and most of the EU, which gives consumers room to buy expensive models. Europe is somewhere in between. Their consumers are generally

concerned about affordability, and sales have been spurred in markets where EV's have become competitive in lifetime costs with ICEs. Nevertheless, European automakers needed to comply with the EU emission regulation and boost the EV models available. These newer local models have been popular in the EU, which shows in their relative market share.

In general, these trends show that domestically produced vehicles have a strong edge in their local EV market. However, Tesla is an outlier in this case because its cars remain the most dominant models within the top end of all three markets by quite a wide margin. This shows that the American car company has ubiquitous acceptability. Major European manufacturers mirror some of this within the Chinese and American markets with the prominence of some German brands. However, China is the laggard in this case, as no Chinese produced model had any leading presence in either the American or European markets.

There are also considerable differences in industrial policy towards securing Li-ion batteries. China was arguably the first to develop a comprehensive industrial policy to develop a local battery industry. This is seen because they are the only one of the three actors to have not only one but two nationally owned Tier 1 battery producers. The EU and US do not have any companies like this, but they have close relations with Korea and Japan – home to the remaining Tier 1 battery producers. At the same time, China also has the substantive majority of global battery production capacity. The EU's formation of the European Battery Alliance is a step to counteract this, and it shows some signs of early progress as the EU is set to become the second largest global producer of batteries within the next few years. The US has also taken steps to address it as the Biden administration recently launched a national Li-ion blueprint. However, the US will have to move quickly to make up for several years of inaction. Despite these efforts, it is unlikely that China will have a significantly reduced share in global production in the medium future.

Although this is not inherently a problem, despite the concerns of China's dominance over this sector, it must be remembered that Chinese demand for Li-ion batteries will continue to grow far beyond both the EU and the US. To this end, Chinese efforts to scale up battery production is more of a tool to secure a long-term supply for the domestic market to ensure that China can continue developing. This should not be considered as a blunt tool of state power. While China's monopoly position can technically be used in such a way, it is not effective in the long term to use such instruments bluntly because trading partners will search for reliable alternatives. Nevertheless, there is a problem with being too dependent on importing such essential components as batteries – especially considering the need to decarbonize transport. The EU and the US must find the appropriate balance in this regard. While they must aim to secure a degree of strategic independence by reinforcing self-sufficiency, they need to do so in an economically

viable way. Blindly supporting weak national champions reduces competition and slows the rate of innovation when it is desperately needed to effectively decarbonize.

5.0. Conclusion

Major economies recognize that to decarbonize their transportation sector, they need a mass introduction of EVs. This connects a secure energy transition that hinges on Li-ion batteries to the automotive sector, which has historically been the center of industrial policies. As this link becomes apparent, competition has intensified as major geo-economic actors have developed comprehensive strategies to secure their market position. China, the EU, and the US are set to be the most important actors in this domain, and how their strategies unfold will determine how much of the world accesses EVs. Although these three share the intention to decarbonize, there are also considerable differences in their paths to building domestic EV and battery industries.

Chinese policymakers were early to act, and they quickly established a substantial lead over the market. Central control and deep financial commitment allowed them to reach ambitious targets much earlier than their counterparts. At the same time, a deep connection between the state and industry allowed the Chinese to forge local champions into world leaders of innovation. In contrast, the EU as a bloc has struggled to overcome the barriers of collective coordination. While some Member States innovated policy solutions, others have fallen behind. Despite the gap, the EU has exhibited a strong ability to leverage long term regulatory planning to send clear signals to private actors, which has helped them keep abreast long-term targets. At the same time, they have also been willing to respond to import dependency with the full force of a collective entity. Conversely, the US has gone back and forth between policy innovation and policy removal. The struggle of political partisanship weakens EV uptake and has put the US behind China and the EU. Nevertheless, the US has a robust private sector and strong sub-national entities that have pushed against partisan gridlock and spurred adoption through radical innovation. Companies like Tesla will likely keep America at the forefront of innovation – but this will remain less than it could be so long as partisanship obstructs government processes.

Although this analysis has covered a wide range of issues and policy developments, the totality of the EV space across these three geo-economic blocs is far beyond the scope of any single paper. Accordingly, future work should build on this by investigating how rules of local content requirements are used to reinforce self-sufficiency across the EV value chain – especially in conjunction with steps towards advanced battery recycling.

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