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Navigating transformative shifts in the automotive supply chain

Building resilient and sustainable supply chains to adapt to EV-induced changes

Metropolia university of applied sciences

Bachelor's thesis

International Business and Logistics

December 2024

Abstract

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Title:	Navigating transformative shifts in the automotive supply chain
Number of Pages:	54 pages
Date:	December 2024
Degree:	Bachelor of Business Administration
Degree Programme:	International Business and Logistics
Specialisation option:	Supply chain Management
Instructor:	Kevin McIntire, Senior Lecturer

This study aims to identify the potential challenges and risks associated with the transition from internal combustion engine Vehicles (ICEVs) to battery electric Vehicles (BEVs) from the perspectives of European vehicle producers' supply chain management. It explores the geographical distribution of suppliers, the structure of the BEV supply chain, and potential shifts in power dynamics between suppliers and automakers due to changes in demands for new types of components. Additionally, this study aims to explore ways to build a resilient supply chain for electric vehicles (EV) batteries, particularly addressing structural vulnerability and potential risks within the global supply chain. The study explores Finland's potential role as a key battery supplier to the European Union (EU) market, considering the country's stringent environmental policies and its extensive expertise in mining and the energy sector.
The study begins with the current market analysis and prospects of BEV in four key markets, namely the United States (US), China, the European Economic Area (EEA), and Japan. The study then delves into the fundamentals of the existing automotive supply chain for ICEVs, comparing them to the BEV supply chain structures. A supply chain risk analysis based on five external elements is conducted to seek solutions for building resilient supply chains in the following chapter.
The key takeaways of this study include significant dependency on China, easier market entry due to component modularization, and the necessity of overhauling the existing automotive supply chain, including the potential phasing out of current suppliers.
The study concludes by emphasizing the importance of multi-sourcing for key components and diversifying supply sources to achieve both carbon neutrality and supply chain resilience while mitigating supply risks. As one of the promising and viable solutions, the study proposes sourcing battery materials in Finland. Amidst the turbulence of comprehensive reform in the automotive industry, meticulous global coordination and the establishment of an agile supply chain are vital to overcoming environmental and economic challenges.

Keywords: automotive, electric vehicle (EV), battery electric vehicle (BEV), supply chain resilience, sustainability,

The originality of this thesis has been checked using Turnitin Originality Check service.

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Glossary

AC	Alternating current
ACEA	The European automobile manufacturers' association
BEV	Battery electric vehicle
COP21	The 21st conference of Parties
CPV	Content per vehicle
CSR	Corporate and social Responsibility
D.C.	District of Colombia
DC	Direct current
DRC	Democratic Republic of Congo
ECU	Electronic control unit
EEA	European economic area
ESG	Environmental, social, and governance
EU	The European Union
EV	Electric vehicle
FCV	Fuel cell electric vehicle
FLSA	Fair labour standards act
GHG	Greenhouse gas

GPM	Grams per mile
HV	Hybrid vehicle
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
ICT	Information and communication technologies
IEA	International energy agency
IoT	Internet of things
IRS	Internal revenue service
MG	Morris Garages
MY	Model year
NAOF	National audit office of Finland
NBB	Nordic battery belt
OECD	Organisation for economic co-operation and development
OSH	Occupational safety and health
PESTLE	Political, economic, social, technological, legal, environmental
PHEV	Plugin hybrid electric vehicle
RPM	Revolution per minute
SC	Supply chain
SDGs	sustainable development goals

SEC	Securities and exchange commission
SOX	The Sarbanes-Oxley act 2002
SUV	Sport utility vehicles
TBL	The triple bottom line
TPS	Toyota production systems
TQC	Total quality control
UK	the United Kingdom
US	the United States
VC	Value chain
ZEV	Zero emission vehicle

1 Introduction

The automotive industry is transforming toward new business models and technologies, propelled by increasing awareness of sustainability in consumer sentiment and the subsequent surge in the global popularity of electric vehicles (EVs). This profound change aligns with the United Nation (UN) declaration of the 2030 Agenda for sustainable development goals (SDGs) (United Nations, 2023b) and the significant outcomes of the 21st conference of Parties (COP21) in 2015 (United Nations, 2023a), accelerating global trends for Environmental, Social, and Governance (ESG) investments.

The electric car market is seeing significant growth as sales exceeded 10 million in 2022. A total of 14% of all new cars sold were electric in 2022, up from around 9% in 2021 and less than 5% in 2020 (IEA, 2023). According to the International Energy Agency (IEA) (2024), every other car sold globally in 2035 is set to be electric based on today’s energy, climate, and industrial policy settings.

However, the rapid and aggressive transition to EVs raises a range of concerns regarding global automotive supply chains. Unlike traditional cars, EVs are equipped with cutting-edge technologies, including new types of components such as electric motors and power electronics controllers, as well as other parts that were traditionally not integral to the automotive supply chain. The demand for these new types of components necessitates a transformation within the existing automotive supply chain to align with the requirements of the future (Nikkei, 2023a).

This study explores upcoming changes and challenges in the global automotive supply chain due to the transition to EVs, with a particular focus on supply chain resilience amid uncertain economic and geopolitical contexts. It also aims to identify major challenges faced by European automakers in establishing EV supply chain. In conclusion, it offers suggestions for diversifying the sources of battery materials by sourcing minerals from Finland, enabling European automakers to achieve harmonious coexistence with EVs.

2 Global EV market research

2.1 EV trends and change in global EV markets

The EV market has seen dramatic growth in recent years and is expected to grow at a considerable pace over the coming decades. According to IEA (2024), EV sales in the first quarter of 2024 grew by around 25% compared with the first quarter of 2023, similar to the year-on-year growth seen in the same period in 2022. This growth has occurred despite various concerns about the industry's pace of growth, tight profit margins, volatile battery metal prices, high inflation, and phase-out of purchase incentives in some countries. Figure 1 below shows the quarterly EV sales by region between 2021 and 2024. It demonstrates strong signs of growth, especially in China.

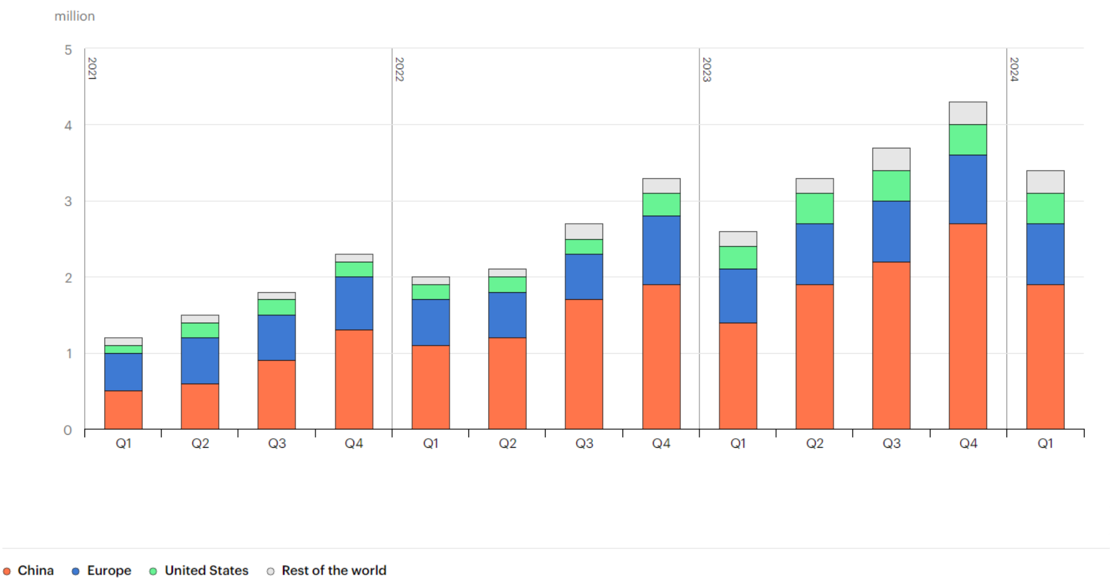


Figure 1 Quarterly electric car sales by region, 2021-2024 (IEA, 2024)

This emerging trend of vehicle electrification comes primarily from environmental concerns such as air pollution, greenhouse gas (GHG) emissions that cause global warming, and volatile energy prices. As figure 2 shows, 71.7% of transportation GHG emissions are caused by road transportation, of which 60.6% are generated from passenger cars (European Parliament, 2019).

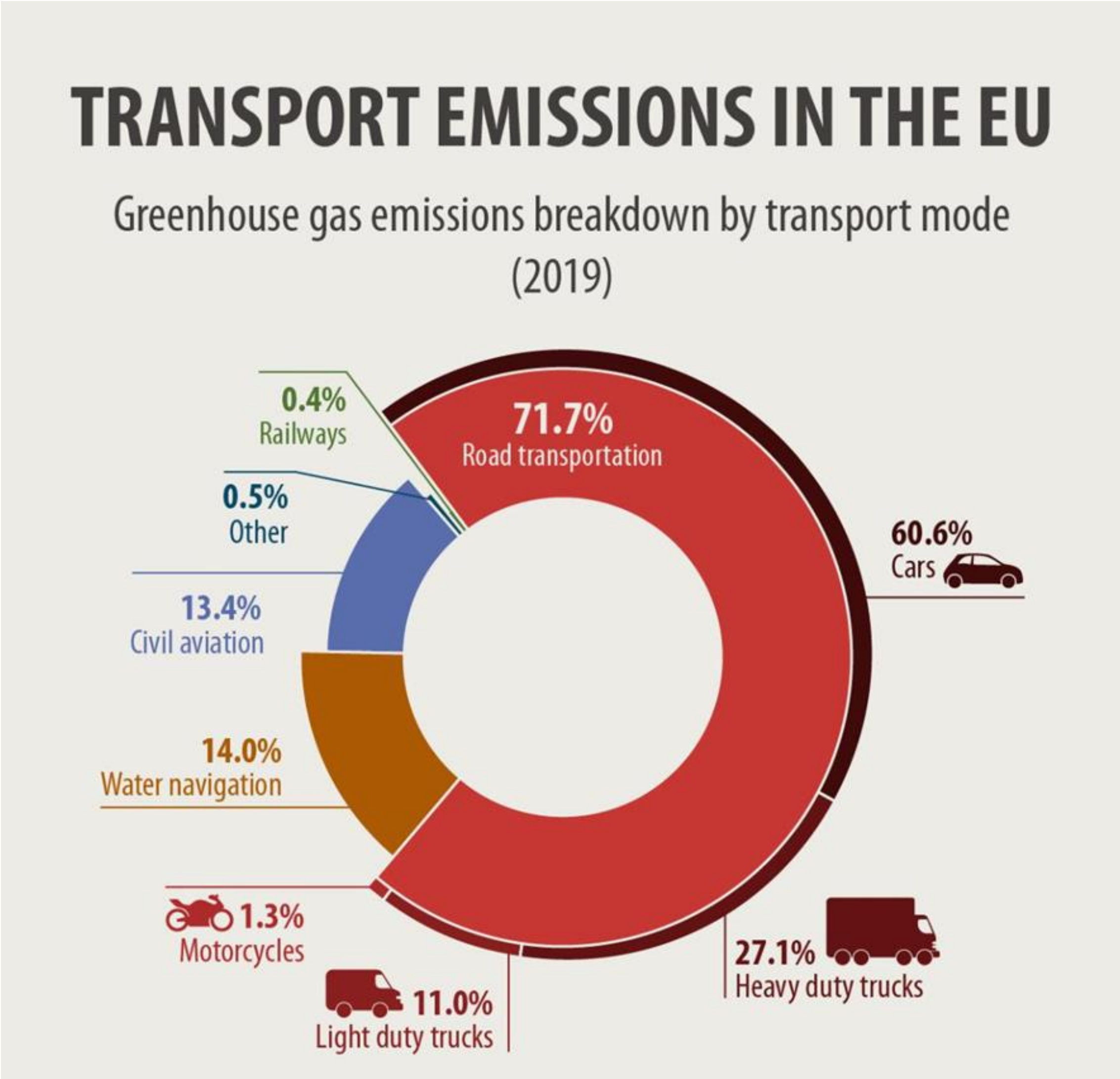


Figure 2 Transport emissions in the EU in 2019 (European Parliament, 2019)

According to European Economic Area EEA (2024), GHG emissions from EVs were about 17-30% lower than the emissions of ICEVs, despite their energy-intensive manufacturing process. Considering the volume of emissions from passenger cars, transitioning to EVs can bring about tremendous benefits. Based on the above data, the following calculation can be derived.

71.7% from total GHG emission * 60.6% from passenger cars = 43.45% of total transportation GHG emissions are caused by passenger vehicles.43.45%* 0.3 (30% reduction) = 13% of the total transportation GHG emissions will be reduced if all ICEVs are replaced BY EVs.

- 20% of transportation GHG emissions will be reduced if all road vehicles, including passenger vehicles and trucks, are replaced with EVs.

The production of electric cars is also expected to become more efficient, and the production of electricity will become cleaner with the use of renewable energy and energy-efficient production methods. The life-cycle emissions of a typical EV could be cut by at least 73% by 2050 (EEA, 2023).

Over-reliance on fossil fuels is also a serious concern since the world's oil reserve is estimated to be depleted by 2052 if we consume at the current rate (Kuo, 2019).

2.2 EV markets and prospects by region

2.2.1 United States

The United States (US), the third-largest EV market, experienced a 55% increase in 2022, reaching a market share of 8%. EV sales are expected to continue growing in the US, thanks to successive policies accelerating their adoption (IEA, 2024). In the US, the Internal Revenue Service (IRS) tax credit combined with the California's Advanced Clean Cars II (ACC II), adopted by twelve other states and Washington, district of Colombia (D.C.), will begin to further increase zero-emission vehicle sales, with the stated aim of reaching 100% by 2035. ACC II aims for all new passenger cars, trucks, and sport utility vehicles (SUVs) sold in California to have zero emissions by 2035 (California Air Resources Board, 2024).

In 2024, the IRS revised the Inflation Reduction Act (IRA) to offer tax credits of 7500 USD if a consumer purchases a new, qualified plug-in EV or fuel cell electric vehicle (FCV) in 2023 or after (IRS, 2024). However, to qualify for the tax credit, vehicle assembly must take place in North America and meet the critical minerals and battery components requirements (IEA, 2024). These strict requirements aim to reshore vehicle production and a major part of the supply chains back to the US.

Additionally, the US Environmental Protection Agency (EPA) proposed more stringent new emissions standards for both light-duty vehicles and medium-duty vehicles for the Model Years (MYs) 2027 through 2032.These standards are projected to lead to an industry-wide average target for the light-duty fleet of 82 grams per mile (GPM) of CO2 in MY 2032, representing a 56% reduction in projected fleet average GHG emissions target levels relative to the existing MY 2026 standards (United States Environmental Protection Agency, 2023). The new GHG emissions standards are set to further increase EV share in the US market.

Overall, IEA projects that the US EV sales share across all modes except 2- and 3-wheels vehicles will reach more than 70% in 2035 (IEA, 2024).

2.2.2 China

China's influence in the global EV industry has experienced a significant upswing. In 2022, new EV sales in Chinese domestic market surged by 82%, constituting approximately 60% of the total global electric car sales (IEA, 2023). With the current momentum in EV sales, China is expected to surpass a 50% EV market share as soon as 2025 (IEA, 2024).

Propelled by enduring industry promotion policies and substantial subsidies, China has successfully positioned itself as the world’s foremost EV market and a pivotal player in the global EV value chain. According to AlixPartners, 57 billion USD was allocated by the Chinese government between 2016 and 2022 for EVs and hybrid vehicle subsidies (Goh, 2023). In 2023, China announced a substantial 72.3 billion USD tax incentive package, offering consumers with tax breaks for EVs and environmentally friendly vehicles to stimulate EV sales (Cyrill, 2023). This substantial investment not only fuelled expansion of the domestic EV market but also attracted substantial manufacturing investment, solidifying China's dominance in the EV sector.

However, the substantial state subsidies led to a notable consequence, as the price of EVs manufactured in China became about 20% more affordable compared to their European counterparts, sparking controversy (Goh, 2023). In 2024, the European Union imposed additional tariffs on manufacturers range from 17.4% to 37.6%, which is on top of a 10% duty that was already in place for all electric cars imported from China (Silva, 2024). EU officials stated that the increase in tariffs was driven by concerns over "unfair subsidisation" which allowed China-made EVs to be sold at significantly lower prices than ones produced within the EU (Silva, 2024).

The domestic battery market in China has also become saturated with an increasing number of new battery manufacturers ramping up production capacity, leading to a decline in battery prices (Sekine, 2023).

Amid growing concerns about business risks with China due to escalating trade tensions and geopolitical conflicts, an increasing number of international companies heavily dependent on China began expanding their manufacturing and sourcing operations to additional countries such as Thailand, Vietnam, and India (DHL, 2024). This move aims at mitigating risks and reducing reliance on a single market (DHL, 2024). This strategy, known as 'China + 1,' has gained prominence in response to logistical challenges from COVID-19 and escalating trade tensions (DHL, 2024).

China's strategic investments and subsidies have solidified its dominance in the global EV market. However, its competitive pricing and significant influence on the global EV supply chain have sparked international controversy, potentially prompting companies to move away from China.

2.2.3 Europe

Europe stands as the world's second-largest EV market, comprising a 25% share of global EV sales (IEA, 2023). Some markets move even faster, such as the Nordics market where EV share of car sales will reach 89% from 2022 to 2026, and the German market will rise to 59% (McKerracher, 2023).

The European Union (EU) adopted the European Green Deal in 2019, a set of proposals aimed at transforming Europe into a climate-neutral continent by 2050. It underscores a commitment to limiting global warming to 1.5 °C and substantively reducing GHG emissions (European Parliament, 2022).

According to The European automobile manufacturers' association (ACEA) (2022), 21 EU member states offer incentives for the purchase of EVs, whereas 6 countries in the EU, namely Bulgaria, Denmark, Estonia, Latvia, Malta, and Slovakia, do not provide any purchase incentives as of 2024.

Due to its high demand for EVs, Europe has recently become a key export market for Chinese automakers, which are subject to US trade restrictions (Goh, 2023). However, there are also criticisms of market distortions and unfair competition caused by China's overwhelming dominance, arguing that it could hinder efforts to develop the potential of EV manufacturers in the EU (European Commission, 2023). Following this move, the European Commission introduced tariffs of up to 37.6% on EV imports from China that took effect in July 2024, aiming to restore fair competition in the market (Teng, 2024).

In fact, many EVs imported from China to Europe are manufactured by foreign carmakers (Zhou, 2023). According to a report by the Center for Strategic & International Studies, 32,000 Chinese-origin EVs were sold in the first half of 2023 in Germany (Zhou, 2023). However, the research found that only 9% out of 32,000 cars belonged to a Chinese brand (Zhou, 2023). Most of them were from Chinese-owned European brands such as Morris Garages (MG) or Polestar, joint ventures between European and Chinese companies, and Teslas manufactured in Shanghai (Zhou, 2023). According to EV-volumes.com, the EU is the largest export market for China-made Tesla EVs, accounting for a 9.1% market share in Europe in January (Teng, 2024). The statistic shows that European automakers are incorporating China as part of their value chain due to the relatively high cost of production in the EU, which is estimated to be 40% more expensive compared to EV production in China (Zhou, 2023). The newly imposed tax may lead western automakers to transfer production to other countries, as a part of surging trend of China + 1 strategy which was described in Chapter 2.2.2 (DHL, 2024).

Despite potential impediments, the EV sales share in the EU across all modes except 2- and 3- wheels vehicles are expected to grow up to 85 - 90% by 2035 (IEA, 2024).

2.2.4 Japan

In Japan, the adoption of EVs to the market is progressing at a slower pace, compared to other markets. In 2023, the total number of EV sales reached a record 88,535 vehicles, accounting for 2.2% of all new passenger vehicles sold in Japan (Take, 2024). Although EV share increased, it is still a fraction of the entire market. Taking Germany as an example, 524,219 units of battery electric vehicles (BEVs) were sold in Germany in 2023, accounting for 18.4% of the total cars sold in Germany in 2023 (Bekker, 2024). There are various reasons for the slow adoption of EVs in Japan, including a shortage of EV charging stations which has remained unchanged since 2018 (NHK, 2023), the relatively high price of electricity, lengthy charging time, and limited driving range with current models (NHK, 2023).

However, the primary reason for Japan’s slow adoption of BEVs is associated with a reluctance of its policymakers and domestic automotive industrial leaders. The main arguments are the scepticism about potential profitability and environmental superiority (Dooley and Ueno, 2021). According to Toyota's CEO, Akio Toyoda, EVs are only as clean as the electricity that powers them and the factories where they are built (cited in Dooley and Ueno, 2021). As Japan's manufacturing industry depends heavily on electricity generated by fossil fuels, the environmental benefits from the transition to BEV will remain marginal (cited in Dooley and Ueno, 2021).

Moreover, Japan relies heavily on imports from overseas for almost all major energy resources (Institute of Energy Economic of Japan, 2023:2). As of 2022, Japan's energy self-sufficiency ratio was 12.6% with heavy reliance on oils, coals, and natural gas as its primary source of energy (Institute of Energy Economic of Japan, 2023:2). The nation's future projections show the planned increase in nuclear and renewable electricity, aiming to increase its energy self-sufficient ratio to 17% by 2024 (Institute of Energy Economic of Japan, 2023:2). Nonetheless, their energy self-sufficient ratio remains low amongst the organisation for economic co-operation and development (OECD) member states. Figure 4 shows comparisons of primary energy self-sufficiency ratios among OECD member countries in 2020, illustrating Japan's heavy reliance on imported energy resources.

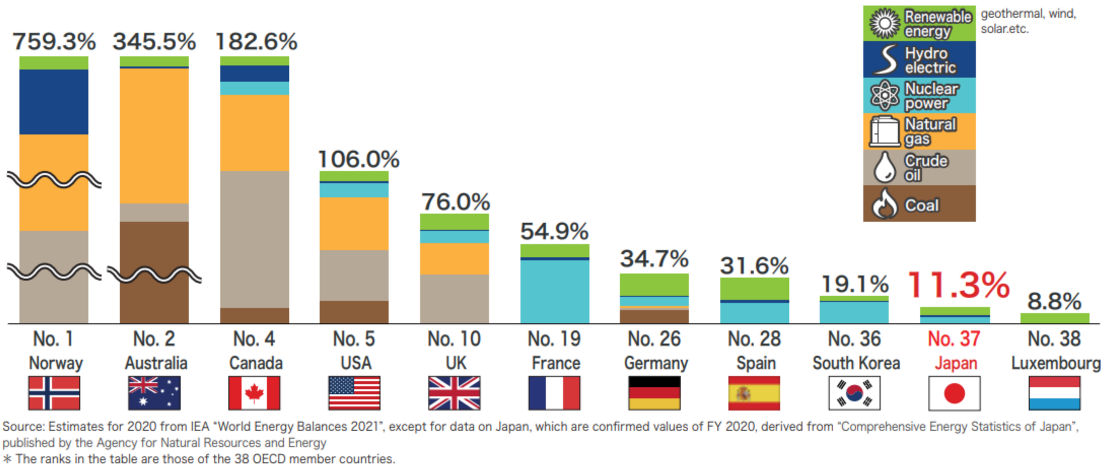


Figure 3 Comparisons of primary energy self-sufficiency ratios among major nations in 2020 (Institute of Energy Economic of Japan, 2023)

Japan's robust, energy-intensive manufacturing industry, which consumes 40% of the total energy consumption, places a strong emphasis on minimizing energy usage. It is also characterized by the philosophy of Lean management, continuously identifying and eliminating sources of wastes to optimise its value-adding operations (Nicholas, 2018:3). This emphasis consequently drives the need for the utilisation of highly energy-efficient technologies such as Plug-in Hybrid Vehicles (PHEV) and Hybrid Vehicles (HEV), while at the same time limiting the commercial viability of EVs (Dooley and Ueno, 2021).

From automakers' perspective, transitioning to the fully electronic vehicles means abandoning the country's enormous investments in hybrid technology and its competitive advantages in gasoline-electric hybrid models (Doorey and Ueno, 2021). Making the shift from building hybrids to building all-electric vehicles in Japan will be executed incrementally, due to the automotive industry's significance to the country's economy.

Japan's Green Growth Strategy aims for all new car sales to be electric or partially electric by 2035 (IEA, 2024). This includes BEVs, FCEV, as well as PHEV and HEVs (IEA, 2024). PHEV and HEV are designed to switch from one power source to another to maximize both fuel efficiency and energy efficiency (Momota, 2023). From the perspective of the Japanese industry and the sentiments of Japanese consumers, the priority is to maximize the energy efficiency of vehicles that align with their lifestyles and needs, while promoting carbon neutrality to achieve environmental goals (Momota, 2023). Therefore, maintaining diverse options in the market is rolled out to be Japan's roadmap to achieve carbon neutrality for the near future. The strategy not only balance the skewness in energy demand by lessening the burden on electricity demand, but also enhance resilience of Japan's economy against energy crisis and trade tensions (Momota, 2023).

2.3 Decarbonisation targets by region

EU and US have passed legislation to match their electrification ambitions towards zero CO2 emissions for new passenger vehicles and light commercial vehicles by 2035 (IEA, 2024). At present, only BEV and FCV are counted as Zero Emission Vehicle (ZEV), which EU, the United Kingdom (UK) and US aim to achieve (California Air Resources Board, 2024). Table 1 below summarises the decarbonisation targets of each state.

Table 1 Decarbonisation target in automotive sector by region (Momota, 2023)

<table>
<tr><th>Geographical Area</th><th>Target year</th><th>Target</th><th>FCV</th><th>EV</th><th>PHEV</th><th>HEV</th><th>ICE</th></tr>
<tr><td rowspan="2">Japan</td><td>2030</td><td>HEV: 30~40%
EV & PHEV: 20~30%
FCV: ~3%</td><td>~3%</td><td colspan="2">20~30%</td><td>30~40%</td><td>30~50%</td></tr>
<tr><td>2035</td><td>EV, PHEV, FCV, HEV 100%</td><td colspan="4">100%</td><td>N/A</td></tr>
<tr><td rowspan="3">US</td><td>2030</td><td>EV, PHEV, FCV: 50%</td><td colspan="3">50%</td><td colspan="2">50%</td></tr>
<tr><td>2030 (California)</td><td>EV, PHEV, FCV: 100%</td><td colspan="3">100%</td><td>N/A</td><td>N/A</td></tr>
<tr><td>2035</td><td>EV, FCV (ZEV): 100%</td><td colspan="2">100%</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">China</td><td>2025</td><td>EV, PHEV, FCV: 20%</td><td colspan="3">20%</td><td></td><td></td></tr>
<tr><td>2035</td><td>HEV: 50%
EV, PHEV, FCV: 50%</td><td colspan="3">50%</td><td>50%</td><td>N/A</td></tr>
<tr><td rowspan="2">EU</td><td>2030</td><td>EV, FCV (ZEV): 50~55%</td><td colspan="2">50~55%</td><td>N/A</td><td></td><td></td></tr>
<tr><td>2035</td><td>EV, FCV (ZEV): 100%</td><td colspan="2">100%</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="2">UK</td><td>2030</td><td>EV, FCV (ZEV): 70~80%</td><td colspan="2">70~80%</td><td></td><td></td><td></td></tr>
<tr><td>2035</td><td>EV, FCV (ZEV): 100%</td><td colspan="2">100%</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

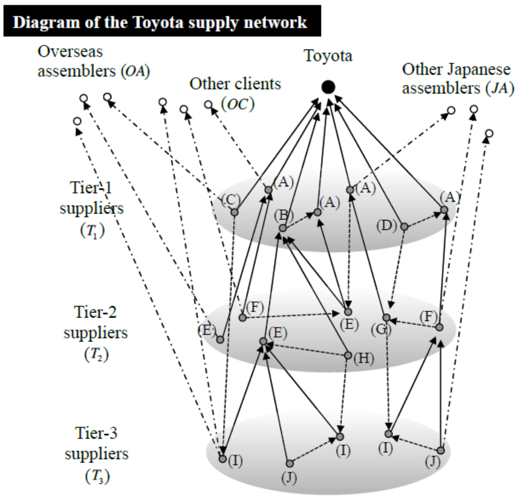
As the EV market is becoming increasingly competitive, an increasing number of new entrants from other emerging markets are anticipated to introduce affordable EV models shortly (IEA, 2023). In the rapidly expanding and emerging EV industry, countries are vying to take the lead, striving to stay ahead of the curve.

3 Supply chains in the automotive industry

The EV supply chain is structured differently from the traditional automotive supply chain due to its unique material and technology requirements, necessitating a restructuring for existing automakers to transition from traditional ICEVs to BEVs. In the following chapters, the structure of both ICEV and BEV Supply chains, along with their major differences, will be clarified to identify the roadblocks that need to be overcome to transition from ICEV and EV manufacturing.

3.1 Toyota’s traditional supply chain structure and unique challenges

The supply chain in the automotive sector is intricate due to its specialization and the vast variety of components used. A single car produced by Toyota consists of approximately 30,000 parts if every small part such as screws is counted (Toyota, 2024b). Each one of these parts used for Toyota’s car requires the highest quality standards under the Total Quality Control (TQC), based on their core philosophy to set their customers' interest and safety as the top priority (Toyota, 2024c). To deliver customers the highest quality products on time, Toyota maintains its extensive supplier network through Toyota Production Systems (TPS), also known as Lean Management, which requires long-term, collaborative supplier partnerships which function as an integral element of the production system (Nicholas, 2018:12). Figure 5 shows the diagram of Toyota supply network (Kito, 2014:9). Kito further explains that 29% of ties within the Toyota network are lateral ties, which connect firms in different tiers. This fact demonstrates the “fuzziness” of the tier boundaries and the resulting complexity of the whole supply network (Kito, 2014:9).



Distribution of different types of firms

Firm type		Number of Firms	
T_1 (580)	A	218	: supplying no other Toyota suppliers
	B	258	: also supplying other T_1
	C	12	: also supplying T_2 and/or T_3
	D	92	: also supplying other T_1 as well as T_2 and/or T_3
T_2 (1477)	E	1130	: supplying none of T_2 and T_3
	F	329	: also supplying other T_2
	G	5	: also supplying T_3
	H	12	: also supplying other T_2 as well as T_3
T_3 (136)	I	133	: supplying none of other T_3
	J	3	: also supplying other T_3
JA		12	
OA		155	
OC		749	

Figure 4: Diagram of Toyota supply network (Kito, 2014:10)

Toyota’s supply network structure is called ‘Keiretsu’, the distinctive formation of exclusive relationships between a Japanese car assembler and its suppliers (Kito, 2014:2). These suppliers are present around the world, supplying each other within the Keiretsu network as well as various other clients, resulting in the formation of a complexly intertwined network (Kito, 2014:20). As of 2021, 6380 tier-1 suppliers, 35,047 tier-2 suppliers are reported as direct and indirect suppliers for Toyota group which includes 15 major affiliated and subsidiary companies (Teikoku data bank, 2021). Among those tier-1 suppliers, software development service provider has the largest segment, 296 companies, which accounts for 4.6% of the total. In recent years, the demand for embedded software, particularly for Electronic Control Units (ECUs) involved in system control, has surged due to growing demand for electrification, and various electronic features such as autonomous driving, as Toyota focuses on advancements in hybrid vehicles (HV), fuel cell vehicles (FCV), and other cutting-edge technologies.

In summary, traditional carmakers will face numerous challenges before shifting their production to EVs. New suppliers will need to be selected, existing suppliers phased out, employees retrained, significant investment in equipment will be required, and companies must seek new competitive advantages among strong new entrants in the increasingly cutthroat market.

3.2 EV supply chain

In contrast to ICEV, EV requires significantly fewer components to build. The number of parts required for EV is approximately 20,000 pcs or less, cut by 30% compared to ICEV (IEA, 2023). The main reason for the reduction in the required components is the powertrain system. ICE powertrain consists of over 1000 components, whereas EV powertrain generally uses only a few hundred parts (Küpper, 2020). Figure 6 below shows the comparison image of ICE and EV powertrain components.

Figure 5: ICE and EV power train components comparison image (Glossinger, 2023)

The engine and auxiliary systems such as alternator, starter, and fuel and exhaust systems used to be the source of the automaker's competitive advantages over traditional ICEVs and will be replaced with a battery pack and an electric motor (Küpper, 2020). In addition, multispeed gearboxes used in ICEVs are replaced with a single-speed transmission in BEVs since the power output of electric motors is efficient and consistent across a much broader range of revolution per minute (RPM) than conventional ICEs (Küpper, 2020). EVs are also equipped with Power Electronics such as direct current (DC) to DC and DC to alternating current (AC) converters and power electronics controllers (Küpper, 2020). Those units are provided as a module, rather than an individual component. In Toyota's ICEV production, 300 to 550 parts are sourced from suppliers to assemble engine units in their in-house production lines, which requires a prominent level of expertise and industrial know-hows to maximise the vehicle's performance (Toyota, 2023b).

In EV production, on the other hand, the process is replaced with a ready-made electric motor unit. This transition not only affects their supply chain but also has a considerable impact on automakers' competitive advantages since any company can purchase the same module to build EVs (Fujisaka, 2023:37).

Moreover, new parts specific to EVs are not sourced from automotive suppliers but are supplied by electronics companies. Consequently, profound changes in the automotive supply chain are expected to occur. Firstly, new entrants in the automotive supply chain fundamentally change the power dynamics of automakers and suppliers (Fujisaka, 2023:36). For example, Toyota has a very robust, interdependent supplier network called 'Keiretsu' which naturally excludes new entrants from outside their network, which in return bolsters mutual trust and interdependency between automakers and suppliers, providing system-level resilience and robustness (Kito, 2014: 3). However, accepting increasing numbers of new suppliers from other industrial sectors may cause inefficiencies in production control, information flow and a more vulnerable supply network (M&A Online, 2023).

In the pull system of lean management, reaching the minimum required stock level serves as a signal to a producer at an upstream location, allowing production to replenish stock systematically and effectively (Nicholas, 2018:213). However, it is subject to suppliers' efforts to replenish stocks promptly. Considering high demands and strong bargaining power of suppliers, it is challenging to ensure prompt delivery of EV parts just in time for automakers' demands (M&A Online, 2023).

It may also be difficult to obtain detailed information on cost breakdowns and production processes from suppliers outside the affiliated keiretsu network, limiting Toyota's capability of cost leadership (M&A Online, 2023). Therefore, TPS, designed to maximise cost efficiency and optimise operation performance, may face challenges in adapting effectively within the emerging EV supply network (M&A Online, 2023).

4 Battery supply, a key component in EV supply chain

4.1.1 Competition over the EV battery supply chain

The cost of EV batteries is a significant challenge for automakers. According to Küpper (2020:3), the battery system amounts to about one-third of the total BEV content per vehicle (CPV) due to high costs of raw materials. According to Kraljic matrix, an effective tool to develop strategies based on risk level and value (Mangan and Lalwani, 2016:147), battery is considered a strategic item due to its high value and dependency on suppliers. Figure 7 below explains the structure of Kraljic matrix, identifying each product category and its procurement strategy based on the complexity of the market (risk) and strategic importance to purchasing (value).

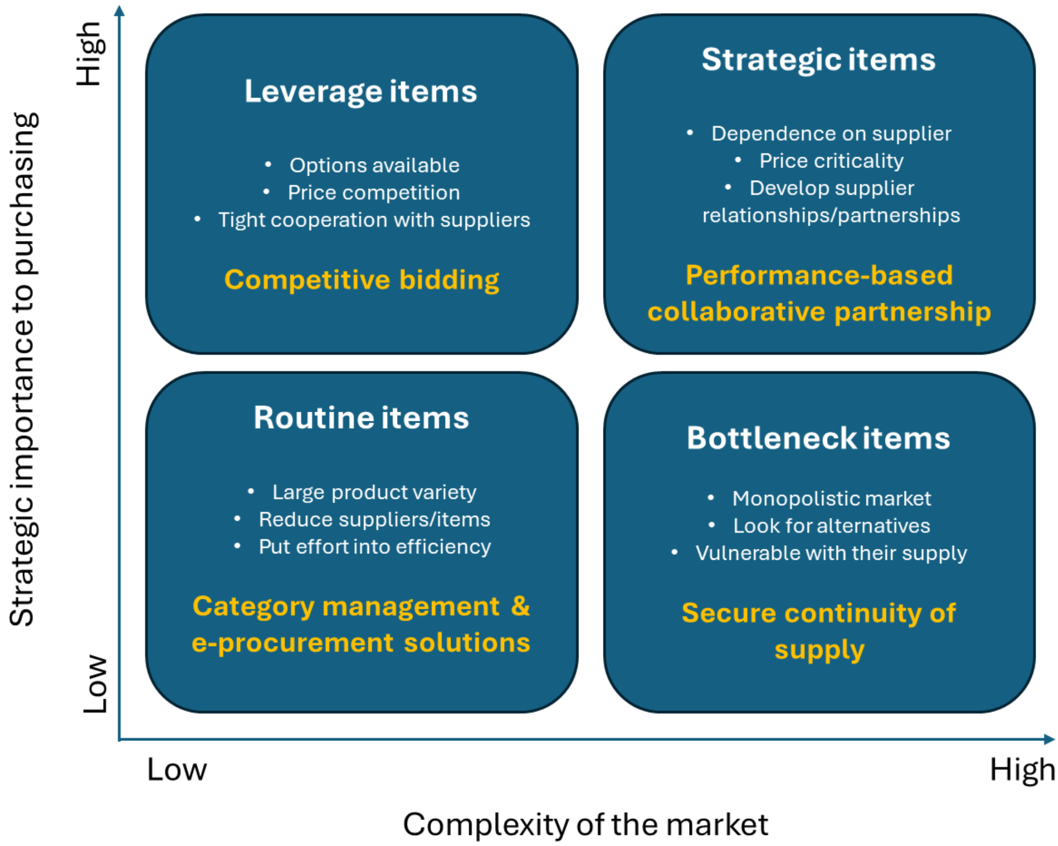


Figure 6 Kraljic matrix (Mangan and Lalwani, 2016:147)

Different strategies are appropriate in each portfolio within each quadrant of the matrix. Strategic items require collaborative partnership with mutual commitment to long-term relationship. ABC analysis, another effective procurement tool to classify items, also identifies EV battery as the most focused category group due to its highest value in the overall cost structure (Mangan and Lalwani, 2016:181).

Some leading EV manufacturers, such as Tesla and BYD, proactively invested in their in-house battery production facilities during the early stage of EV development, providing them with a cost advantage in the intensifying competition within the EV market. Toyota is currently constructing a battery factory in North Carolina, the US, set to commence production in 2025 (Toyota, 2024d). However, despite efforts in its in-house battery production, the demand for the EV battery surpasses the in-house supply. Consequently, cost benefits and effects on securing battery supply from in-house battery production will be constrained (M&A Online, 2023).

4.1.2 China’s presence in the EV supply chain

China not only stands as the largest EV market but also commands a pivotal position in the EV supply chain, boasting over three-quarters of the world’s battery production capacity (Cyrill, 2023). Moreover, China contributes to more than half of the global processing and refining capacity for vital materials like lithium, cobalt, and graphite, which are essential components for EV batteries, highlighting its substantial influence in the EV supply chain (Cyrill, 2023). Since 2008, Beijing has strategically prioritised electrification, positioning itself as a frontrunner in the EV industry (Zhou, 2023). Over the years, the Chinese EV industry has thrived, thanks in part to substantial state subsidies in addition to collaborations with world’s leading automakers, facilitating robust growth and development.

Chinese automakers and suppliers leverage their rich resources, well-established infrastructure, and robust domestic supply chain as competitive advantages (Zhou, 2023). BYD, a Chinese EV battery and the world second largest EV maker, has solidified its position as one of the largest EV battery suppliers, with competitors procuring batteries from BYD at market rates, granting the company a competitive edge in terms of cost (Zhou, 2023).

In summary, China's formidable influence in the EV industry is evident through its establishment of a robust supply chain, including the supply of raw materials for batteries. Consequently, reducing dependency on China has emerged as a crucial consideration for the future development of EV industries in another regions.

5 Supply chain risk management

Chapter 4 explained the strategic item, the ‘Holy grail’ of EV Supply chain, and identified a key player of the critical components. In this chapter, those insights will be applied to the supply chain risk analysis formula to identify the risks across five categories: environmental, economic, societal, security, and technological risks to understand the nature of each risk.

5.1 Supply chain risk definition and classification

Countless sources of risks potentially disrupt supply chains. According to Manners-Bell (2020), risks can be classified to internal and external risks as shown in Table 2.

Table 2 Risk type chart (Manners-Bell, 2020:5)

Internal Risk	**Process**	Management and value-adding activities
	Control	Rules, systems that govern how a firm controls the processes
Supply chain Risk **(External Risk)**	**External** to a firm but **Internal** to the supply chain network	Demand (Downstream) Supply (Upstream)
	External to a firm and the supply chain network	‘Environment’ (e.g. natural disasters, weather, or socio-political)

The internal risks, which are stated as process and control in table 2, are under the control of a company (Manners Bell, 2020:5). Process and control risk is referred to as internal risks to a company, representing management, value-adding activities and rules and corporate governance systems respectively (Manners Bell, 2020:5).

On the other hand, supply chain risks, which specifically affect the extended networks in which most companies in the modern business landscape operate, are external to a firm, resulting in limited visibility and control (Manners-Bell, 2020:5). Supply chain risks encompass fluctuation and volatility in both demand and supply, in addition to various other factors associated with environmental or socio-political situations (Manners-Bell, 2020:5). One issue arises from a lack of visibility both upstream and downstream, such as unexpected large orders to a supplier with limited production capacity or material shortages. Such situations occur more frequently in the forecast-driven operation, rather than demand-driven operation, creating challenges in reacting promptly to changing market conditions due to a lack of shared information (Manners-Bell, 2020:5).

Internal risks and supply chain risks are closely related (Manners-Bell, 2020:5). For example, increasing inventory levels could mitigate external risks such as demand and supply fluctuations, however, it could exacerbate internal risks such as redundancy, wastage, shrinkage, and financing (Manners-Bell, 2020:5). In modern business, globalisation became mainstream in various fields, leading to longer and more complex supply chains, structurally being exposed to inherent risks (Manners-Bell, 2020:11).

5.2 Five elements of supply chain risk

Supply chain risk can be divided into five main categories, namely environmental risks, economic risks, societal risks, security risks, and technological risks (Manners-Bell, 2020:23). This classification bears resemblance to political, economic, social, technological, legal, environmental

(PESTLE) factors, commonly used in business to analyse and monitor macro-environmental factors affecting an organization (The Chartered Institute of Personnel and Development, 2023). Notably, in contrast to the traditional PESTLE factors of Political and Legal, Manners-Bell's (2020:23) supply chain risk classification incorporates security factor, encompassing both aspects that are stated separately. In the following chapters, each risk factor is explained with examples.

5.2.1 Environmental risks

In the context of supply chain risk management, environmental risk factors comprise a wide range of disruptive events, including natural disasters such as extreme weather, hurricanes, earthquakes, floods, and volcanic eruptions (Manners-Bell, 2020:23).

Those events can be categorised into geophysical, hydrological, meteorological, or climatic events (Manners-Bell, 2020:82). The following table lists examples of disruptive events in each category.

Table 3 Environmental event category and type

Event category	Event type
Geophysical events	Earthquakes and tsunamis
Hydrological events	Floods
Meteorological events	Tornados, hurricanes, storms, blizzards, and more.
Climatic events	Heatwaves, droughts, and more.

On some occasions, multiple events across various categories could occur simultaneously, as seen with Hurricane Katrina, which involved a hurricane and floods (Manners-Bell, 2020:82). One significant environmental event that caused severe global supply chain disruption in decades is Japan’s Tohoku earthquake and Tsunami in 2011. The earthquake and the subsequent tsunami devastated the area of northeast Japan, leading to widespread infrastructure destruction, loss of life, and environmental contamination (Ratnapradipa et al, 2012:42). The incident resulted in the temporary suspension of production across a wide range of sectors. Amongst them, the electronics sector was the most severely affected by the incident, causing disruption in semiconductor production (Manners-Bell, 2020:89).

The event not only affected Japan’s domestic supply chain but also the global supply chain, as several key suppliers of automotive electronics to the global industry were located in close proximity to the devastated areas (Manners-Bell, 2020:51). According to Manners-Bell (2020:90), Toyota was the most severely affected by the disaster, resulting in a month-long closure of its factories in the immediate aftermath of the earthquake, followed by a 50% reduction in production output (Manners-Bell, 2020:90). Other automakers such as Nissan-Renault, Honda, General Motors, Chrysler, Ford also experienced supply disruption on a global scale to some extent (Manners-Bell, 2020:91).

Another noteworthy example from the 2011 Tohoku disaster is the shortage of xirallic pigments, popular ingredients for car paints due to their unique shinier and glittery effect (Manners-Bell, 2020:52). The pigments were produced only in one plant in the world, near the Fukushima nuclear reactor, which became off-limit due to the aftermath of the Tsunami (Ratnapradipa et al, 2012:42). This case revealed a lack of visibility below tier 1 and tier 2 suppliers in the industry, as various manufacturers had no clue that they were all reliant on one supplier in a single location (Manners-Bell, 2020:53).

In summary, supply chain disruptions caused by environmental risks underscore the inherent vulnerability of the intricate automotive supply chain. This vulnerability is primarily attributed to its highly localized network, as well as a limited visibility in the lower-tier supplier network. Additionally, the increased reliance on electronic components has led to structural changes in the network (Manners-Bell, 2020:90). Improving visibility throughout the supply chain could be the key to resolve these fundamental problems.

5.2.2 Economic risks

Economic risks in supply chain risk management include demand and supply shocks, oil price volatility, trade restrictions, border delays, and industrial actions such as strikes and more (Manners-Bell, 2020:24). Demand and supply shocks fall into one of the major supply chain risk categories of “External to a firm but Internal to the supply chain network” in Table 2. According to Manners-Bell (2020:5), this type of risks is under the control of a company. With the development of information technologies that enhance end-to-end coordination and overall visibility, the risks associated with demand and supply shocks can be mitigated significantly (Manners-Bell, 2020:12).

Demand shocks, characterized by sudden surges or collapses in the demand for products and services, pose a significant risk to supply chains. The complexity of forecasting their onset and impact on production and supply adds to the challenge (Manners-Bell, 2020:135). With the growing trend of unbundling and outsourcing, the levels of intermediate goods exchanged between companies and across borders are increasing (Manners-Bell, 2020:135). This trend gives rise to common supply chain issues, including the bullwhip effect. The bullwhip effect is a distortion of orders along the supply chain, wherein minor fluctuations in end customer demand result in an amplification of demand upstream (Mangan and Lalwani, 2016:74). This phenomenon is often caused by factors such as lack of visibility in customer’s demand, order batching and various other reasons (Mangan and Lalwani, 2016:74).

Other economic risk factors are listed below:

- Volatile shipping rates and capacity, which could cause supply shocks (Manners-Bell, 2020:138)

- Trade restrictions, such as trade wars, sudden imposition of tariffs, non-tariff barriers, and bans on importing from and exporting to certain countries (Manners-Bell, 2020:141).

- Oil price volatility, impacting on transportation and logistics (Manners-Bell, 2020:140)

- Industrial unrest, considering highly labour intensive and unionized nature of the manufacturing and logistic industry (Manners-Bell, 2020:143).

- Currency fluctuations

While these risks can be mitigated to some extent through utilisation of Information and Communication Technologies (ICT) and meticulous strategizing, it is essential for a business to consistently monitor these economic risk factors to maintain its agility and adapt promptly to changing situations.

5.2.3 Societal risks

Societal risks to the supply chain have been gaining prominence lately, with the increasing awareness of corporate social responsibility (CSR). Businesses with CSR consider ethical consequences of their acts on society (Grant, Trautrims, and Wong, 2023:228). In the past, the main target of most commercial companies was to generate maximum profit for their shareholders, according to

Friedman’s (1962) perspective (Grant et al, 2023:229). However, the traditional business norms began to reshape during the 1970s as businesses started acknowledging the significance of CSR (Grant et al, 2023:229). Amidst the intense competition in the business world, the concept of CSR evolved to address not only social responsibility but also commercial and environmental considerations (Grant et al, 2023:230). This modern approach to corporate sustainability is also represented as the Triple Bottom Line (TBL) (Grant et al, 2023:31).

TBL encompasses profits, the planet, and people. It emphasizes that a business should prioritise maximising shareholder wealth or economic value, while integrating efforts to contribute positively to the environment and society (Grant et al, 2023:32). This approach seeks to achieve long-term natural environment security and uphold proper working and living standards for all human beings (Grant et al, 2023:32). Although it is voluntary due to a lack of legal framework that enforce compliances in social responsibility to businesses, CSR dimension is critical to the supply chain (Grant et al, 2023:229). Global supply chains have created substantial opportunities for businesses and developing countries, fostering economic development. However, they have also introduced challenges, including issues related to working conditions in developing countries, as well as concerns about waste management and pollution (Manners-Bell, 2020:148). With a growing consumer focus on the overall sustainability of products, businesses are now expected to adopt ethical policies that demonstrate their commitment to CSR (Manners-Bell, 2020:148).

5.2.4 Security risks

In the past few years, security risks, such as geopolitical tensions, cargo crime, terrorism, and piracy, have become increasingly prominent in the global supply chain. In Asia, political tension between China and Taiwan is intensifying year on year, as Taiwan favours independence while Beijing has ramped up political and military pressure on Taipei to unify the island with the mainland (Maizland, 2024). Taiwan acts as a critical hub in the technology value chain, with a strong presence of the world’s largest contract semiconductor manufacturer, Taiwan Semiconductor Manufacturing Company (TSMC) (Dow Jones, 2024). These high-end chips form essential components across electronics, from smartphones to cars. To mitigate the geopolitical risks, however, the leading semiconductor giant plans to relocate its facilities partly to Kumamoto, Japan and Phoenix in the US with the help of subsidies from both states (Dow Jones, 2024).

In Europe, various geopolitical risk factors are prevalent. Since 2022, grains, metals, and energy supplies have been affected both locally and globally by the Russian invasion of Ukraine, causing inflation around the world (KPMG, 2024). In 2024, the Red Sea shipping crisis occurred as a result of Houthi rebel attacks on cargo ships and tankers, causing hundreds of vessels to avoid the Suez Canal, one of the world’s most important waterways (J.P.Morgan, 2024). With 30% of global container trade transiting through the Suez Canal, the Red Sea shipping crisis is severely disrupting global supply chains (J.P.Morgan, 2024). The rerouting of cargo ships around Africa’s Cape of Good Hope equates to a roughly 30% increase in transit times, resulting in an approximately 9% reduction in effective global container shipping capacity (J.P.Morgan, 2024).

Numerous political factors cast a shadow over global supply chains. For example, Brexit, US foreign policy, migration and trade policies, tariffs, and taxation all wield considerable influence on the global economy (Manners-Bell, 2020:185). Brexit, the UK’s withdrawal from the EU on January 31, 2020, affected the UK’s economy, including its automotive industry, a critical sector representing 10 percent of the UK’s trade in goods (Manners-Bell, 2020:196). However, Manners-Bell (2020:196) suggests that the impact was marginal due to the high efficiency of the automotive supply chain and the limited proportion of components sourced from the EU. The landscape surrounding the UK’s automotive industry remains unchanged, as the UK and EU economies are closely interdependent in the industry, and structural changes could potentially harm both economies (Manners-Bell, 2020:196).

International supply chains are highly vulnerable to political intervention, particularly in recent years due to challenges posed by populist sentiment advocating for the reshoring of production (Manners-Bell, 2020:205). However, Manners-Bell (2020:205) also asserts that this resistance against global supply chains does not negate the economic advantages of global sourcing, despite the risks and economic burdens imposed by tariffs. This is because businesses often shift from suppliers situated in regions affected by tariffs and restrictions to those in unaffected areas (Manners-Bell, 2020:205).

5.2.5 Technological risks

The major technological risks with the highest potential impact include cyber-attacks and system failures (Manners-Bell, 2020:29). As cars become increasingly connected to the internet, there is a heightened risk that privacy and safety could be compromised (Telang, 2018:3). A study conducted in 2015 revealed the vulnerabilities of connected cars to security threats, as researchers were able to hack into the software of a vehicle over the internet, enabling them to manipulate the vehicles remotely (Telang, 2018:3). In terms of supply chain risks, all third parties pose certain level of risk, such as a lack of adequate security controls among small system development suppliers (Telang, 2018:7). In Chapter 3.1, it is demonstrated that software development service providers constitute the largest segment among Toyota’s tier-1 suppliers, accounting for 4.6% of the total. Given the heavy reliance on suppliers for software development, coupled with an increasing complexity of the supply chain resulting from the adoption of internet of things (IoT), it is imperative to prepare appropriate risk mitigation plans as well as fallback options.

To mitigate these risks, businesses must cultivate a cybersecurity culture within their organizations that acknowledges threats and follows processes to combat them (Telang, 2018:11). Automotive companies should actively monitor their partners' operations for potential security breaches and manage user access to various systems (Telang, 2018:10). Additionally, contracts with smaller vendors are recommended to incorporate audit clauses and mandated testing procedures, as smaller vendors often have less stringent security protocols, posing unique risks (Telang, 2018:10).

5.3 Identified risk factors in EV supply chain

Based on the above definitions, potential Supply chain risks could be summarised as follows:

Demand and supply risk: Fluctuation and volatility in demand and supply, limited visibility toward upstream and downstream.

Environmental risks: Natural disasters, especially if the supply network is highly concentrated in one geographical area.

Economic risks: Trade restrictions, border delays, strikes, political unrest, commodity price fluctuations, currency fluctuations.

Societal risks: CSR, labour conditions, layoffs, waste management and recycling, compliance of suppliers.

Security risks: Geopolitical tensions, cargo crime, terrorism, piracy.

Technological risks: Cyber-attacks, system failures, alternative technologies.

Most of them are common risks in international trading. However, the most critical elements specifically to the EV Supply chain could be economic risks and security risks, considering the level of reliance on a single country and potential impact in the event of risk materialisaiton. To build a resilient EV supply chain, it is imperative to take those risks including its probability and severity into consideration.

6 Supply chain resilience and agility

The supply chain risks listed in the previous chapter can be used to simulate the structure of a resilient and agile Supply chain for EVs. To simulate a risk-tolerant supply chain, the concept of Supply chain resilience and agility will be explained in the following chapters.

6.1 Supply chain resilience

With rapidly evolving technologies and business environments overturning traditional structures and networks within the industry, the automotive sector faces significant challenges in adapting to the new norm. Supply chains, particularly in the fast-changing field such as technology, must maintain resilience to adapt to any disruptive events affecting their networks. Outsourcing, unbundling, and globalization have led to a diversification of production that mitigates any single disaster which has a significant impact on a company’s ability to operate (Manners-Bell, 2020:33). On the other hand, diversification of production also resulted in the lean supply chains to be more prone to catastrophic events, due to their exposure to a greater range of risks (Manners-Bell, 2020:33).

To ensure a company’s ability to promptly adapt to various events that cause supply disruptions, such as unexpected delays or shortages, engineering supply chain resilience is sought by international companies as their strategic goal (Manners-Bell, 2020:32). Supply chain resilience is defined as a system capable of returning to its original state after a major disruption, while maintaining output close to potential throughout and in the aftermath of such a shock (Manners-Bell, 2020:31). It encourages an entire system perspective throughout networks, rather than focusing on a single company for a supply chain to be resilient and competitive (Manners-Bell, 2020:33).

One key aspect of supply chain resilience is to understand its vulnerabilities and address them (Manners-Bell, 2020:32). Risk identification covered in Chapter 5 can be applied to understand risks better. Manners-Bell (2020:32) pointed out that improving supply chain visibility upstream through downstream can be also one of the most effective ways to achieve supply chain resilience. The two key principles to building supply chain resilience are lean and agility, which are explained in the next chapter.

6.2 Supply chain agility

In the context of supply chain management, agility refers to two elements, namely supply chain visibility and supply chain velocity (Christopher and Peck, quoted by Manners-Bell, 2020:33). Supply chain visibility enables businesses to have a clear understanding of demand and supply, as well as inventory levels at each stage (Manners-Bell, 2020:33). Creating visibility requires a prominent level of collaboration throughout the supply chain in addition to supplier’s ethos to audit their suppliers, which are considered lower-pier suppliers from automakers’ perspective (Manners-Bell, 2020:32). Effective communication systems which enable information to be shared seamlessly and promptly throughout the supply chain need be established, so that each node through supply chain is prepared for any unexpected changes in demands (Manners-Bell, 2020:32). By leveraging these strategies, an organization can break silos within the supply chain to providing supply chain visibility.

Supply chain velocity involves a lapse of time between order from a supplier and delivery (Christopher and Peck, quoted by Manners-Bell, 2020:33). This is particularly important in the lean management, as it could accelerate or jeopardise inventory turnover in case of disruptive events. Small-batch quantities, reduction of takt-time, and streamlining production flow are essential to this concept (Manners-Bell, 2020:33).

In summary, resilient Supply chain requires two key elements: lean and agility, both of which are hardly achievable in EV supply chain under the current circumstances. Lean requires close collaboration and precise control over the flow of the entire supply chain. However, due to the dominance of key material providers, the overall flow can be controlled by suppliers, instead of automakers. Agility consists of visibility and velocity and attaining both within the EV industry can be challenging due to its significant dependence on a single country, China. China’s party-state rules the market and regulates all aspects of business, though the degree of intervention varies depending on the industry (Yukyung, 2020:2). The resulting uncertainty and restrictions pose potentially significant obstacles in the EV supply chain.

7 Key elements for building resilient and agile supply chain in the EV revolution

In the previous chapter, the essential elements for building a resilient supply chain and its inherent challenges were explained. Based on these assumptions, this chapter aims to provide author’s suggestions to build a resilient and agile Supply chain to adapt to ever-changing conditions in the EV industry.

7.1 Improved visibility upstream and downstream

To improve visibility, various techniques and technologies could be leveraged. Chapter 6.2 examined the ways to improve visibility, such as a high level of collaboration throughout the supply chain, auditing lower-peer suppliers, integrated ICT systems to communicate seamlessly and more. This section will delve into the visibility associated with corporate compliance, to ensure fair and transparent governance.

In developed nations, various regulations and laws are enforced to protect businesses from potential corporate risks. In the US, the Sarbanes-Oxley Act of 2002 (SOX) applied to all US publicly listed companies and overseas suppliers, mandating full disclosure of all risks to corporate well-being within the business (Mangan and Lalwani, 2016:261). Additionally, the US department of labour also enforces over 180 federal laws, including fair labour standards act (FLSA) and Occupational Safety and Health (OSH) Act, to protect worker's right (US Department of Labor, 2024).

In the EU, stringent laws and regulations are enforced to combat fraud and corruption. For example, EU labour law guarantees fundamental, modernised working rights and protections to all workers in member states (European Commission, 2024b）. Furthermore, the EU audit directive (2014/56/EU) and audit regulation (537/2014/EU) introduced stringent requirements for the statutory audits of businesses in Europe, encouraging professional scepticism and limiting conflicts of interest (European Securities and Markets Authority, 2024). From the above facts, common sets of standards in corporate compliance are found in developed countries.

In developing countries, however, lax enforcement of laws and regulations often leads to inadequate oversight of local low-tier suppliers, resulting in limited visibility across the entire supply chain and an inability to effectively manage risks. For example, many cases that involve unfair labour practices in manufacturers in emerging countries, including Foxconn and Rana Plaza factory, have attracted a great amount of negative publicity (Manners-Bell, 2020:149). The cases unveiled underlying problems associated with complex supply chains extending into emerging countries, including concerns about child labour, prolonged working hours, unfair wages, and inadequate management of employee's health and safety (Manners-Bell, 2020:149).

Another notable example is the issue of conflict-free minerals in the Democratic Republic of Congo (DRC), where the mining industry has been marred by corruption in conflict-affected regions and human rights abuses (Manners-Bell, 2020:159). In some cases, proceeds from mineral sales directly fund armed groups involved in civil conflicts across the region (Manners-Bell, 2020:159). To address this concern, the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 mandated that all publicly listed companies in the US reporting to the Securities and Exchange Commission (SEC) disclose any involvement with conflict minerals from the region (Manners-Bell, 2020:159).

Conflict-free minerals are defined as those that do not finance or benefit armed forces in the region (Manners-Bell, 2020:159). In the EU, legislation similar to the US equivalent aimed at restricting conflict minerals came into effect in 2021 (Manners-Bell, 2020:159). Additionally, the European partnership for responsible minerals was established to facilitate collaboration among all stakeholders involved in the trade of tantalum, tin, tungsten, and gold (3TG), critical minerals exclusively used in high-tech manufacturing (Manners-Bell, 2020:159).

However, these are just the tip of the iceberg, as corruption and unethical practices often occur under the radar. Achieving supply chain agility through improved visibility and velocity could face significant challenges partly due to a lack of a legal framework and ethical standards in local business cultures in emerging countries. As per the Kraljic matrix in Chapter 3.3.1, EV batteries are classified as strategic items that require establishment of performance-based, collaborative relationships with suppliers. While this strategy remains highly effective, alternative approaches such as seeking substitutes for bottleneck items can also be simultaneously pursued, to reduce dependency on risky sources of supply.

To summarise, having a collaborative relationship with high-performing, trustworthy suppliers that commit to ethical practices is imperative to creating visibility upstream and downstream in the supply chain.

7.2 Diversified resource allocation

The biggest challenge in achieving a resilient supply chain in the EV industry is to reduce dependence on China for the most critical components. The whole supply chain involving many automakers will be severely disrupted if any risks materialise. To mitigate risks, multi-sourcing from multiple geographical areas with low correlations in political, economic, and social aspects could be promising and viable solution.

7.2.1 National battery strategy in Finland

As the demand for batteries continues to increase, building a sustainable yet resilient supply chain is perceived as a critical matter for the global economy. Chapter 3.1 examined the current state of EV supply chain and its risks, as well as challenges. Sourcing batteries and raw materials from multiple regions including those of the closest proximity is one way to mitigate area-specific risks, such as natural disasters, logistic disruption or geopolitical events. The Ministry of Economic Affairs and Employment of Finland (2021:7) announced the National Battery Strategy 2025, aiming to strengthen the innovative environment of the battery sector, accelerate Finland’s sustainable and low-carbon economic growth, and support the achievement of climate objectives in transport. Finland has significant minerals reserves including battery minerals such as nickel and cobalt, and a long tradition in mining and refining those reserves (Ministry of Economic Affairs and Employment of Finland, 2021:9). Mining and mineral processing in Finland is strictly regulated and energy-efficient, which reduces PESTLE risks in addition to aligning with EU’s sustainability targets in the battery supply chain (Ministry of Economic Affairs and Employment of Finland, 2021:9). In addition, the nation offers an attractive business and innovation platform with industrial expertise, skilled professionals, well-established domestic battery value chain as represented in the figure 10 below, and world-class leading technology in energy sector (Ministry of Economic Affairs and Employment of Finland, 2021:15).

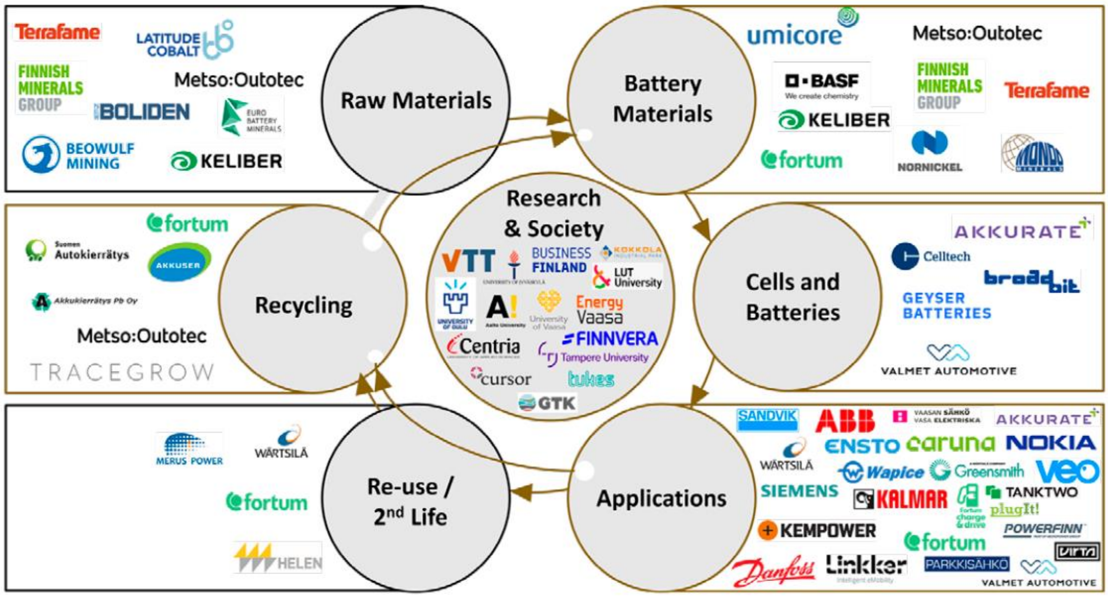


Figure 7 Key players of the Finnish battery value chain (The Ministry of Economic Affairs and Employment of Finland, 2021:13).

This initiative involves cross-border collaboration with Sweden, in response to the emerging logistics flows in the Ostrobothnia region in Finland, stemming from ongoing and forthcoming battery plant establishment (Kvarken Council, 2022). The Nordic Battery Belt (NBB) Logistics project, completed in 2022, laid the foundation for the emerging cross-border regional network to formulate logistical strategies and inventories for sustainable and cost-effective transport systems in the region, which will support the battery industry’s supply chain and reduce the industry’s carbon footprints (Okonkwo, 2022:52).

For example, Wärtsilä, a global leader in innovative technologies and lifecycle solutions for the marine and energy markets, takes a vital role in the downstream of the battery supply chain explained in figure 10. The Finnish-based leading company in sustainable technologies provides state-of-the-art digital energy platform that optimise energy performance in power plants worldwide (Wärtsilä, 2024). Driven by data analytics, the energy storage & optimisation units automatically adjust energy production output, store excess energy, and redistribute them based on multiple data sources including weather, load, and market forecast (Wärtsilä, 2024).

However, cell and battery production, the middle part of the battery supply chain, is still underway. According to the investigation conducted by the National Audit Office of Finland (NAOF) in 2024, the continuous battery value chain, the key objective of the National Battery Strategy 2025, is unlikely to be realized in the next few years, due to the premature status of the construction of a battery cell plant (NAOF, 2024:2). Lack of skilled workforce would be another bottleneck for the growth of Finland's battery sector unless the state takes determined efforts to tackle skilled labour shortage in the battery industry (NAOF, 2024:4).

7.2.2 Finland's mining industry and its potential

Mining in Finland possesses immense potential as described in Chapter 7.2.1. Mining could stimulate local industries and the economy, especially if mines produce chemicals in high demand. However, it comes with various risks which may bring about severe consequences. One of the most outstanding cases is the incident of Talvivaara nickel and zinc mining company, which had two incidents in 2012, resulting in severe environmental consequences (Törmä, Kujala and Kinnunen, 2015: 132). The incident provoked resentment among residents and created distrust not only for the Talvivaara mine but for the mining industry in general (Törmä, et al., 2015: 132). Despite the environmental problems and subsequent corporate restructuring, the Talvivaara mine had a positive cumulative effect on the employment of Kainuu (Törmä et al., 2015:127). The company applied for corporate restructuring towards the end of 2013 and reinvented itself under the new name, ”Terrafame” (Terrafame, 2024). Terrafame set its future strategy in 2018 to focus on manufacturing battery chemicals and supplying battery chemicals to European automakers since 2021, increasing its presence in European Battery Supply chain (Terrafame, 2024). However, Törmä's argument is based on the statistical data and prediction as of 2015, on the assumption of nickel price growing by 9% annually (Törmä, et al. 2015:136). In fact, the market price of nickel on the London Metal

Exchange has fallen markedly since 2022, to the same level as the 2015 average market price for nickel (Terrafame, 2023).

Despite the negative impact of the decreasing price of nickel, the company managed to successfully execute its rehabilitation as planned. Based on Terrafame’s 2023 financial report, the company’s nickel production in 2022 was its record high of 31,550 tonnes (Terrafame, 2022), in line with the company’s long-term production target of 30,000 tonnes by 2022 (Törmä, 2015:136). The company is steering its restructuring while managing risks through diversified product categories: battery chemicals and metal intermediate (Terrafame, 2023:11). Taking all the above aspects into consideration, it can be said that the company is contributing positively to the regional economy.

Overall, cross-border collaboration and the national promotion of the battery industry could yield substantial benefits for local economies, as well as the global battery supply chain. Despite various challenges, Finland, as one of the prominent countries of EU member states, has a great potential to play a pivotal role in transforming the battery supply chain for European automakers into a more sustainable and resilient form.

Conclusion

The study findings indicate that achieving supply chain resilience and agility requires overcoming numerous challenges. Despite the forthcoming challenges, the global automotive industry is forced into a situation where adapting to electrification is essential. The study revealed that, in the EV supply chain, economic and socio-political risks are particularly high among various other risks. In the current distorted supply network that relies heavily on China, even a single risk materialising could have a significant impact worldwide. To build a resilient supply chain for the new era of the automotive industry where EVs are prevalent, this study advocates for diversifying the source of critical materials across different geopolitical regions. In conclusion, procuring key components for EVs, such as batteries, from multiple locations with minimal political and economic correlation is recommended to help existing automakers achieve a resilient EV supply chain. Considering geo-political risks, it is advisable to procure a certain percentage of components from suppliers with the same ethical standards as the manufacturers. The study suggested Finland as the promising supplier of battery minerals for the EU market.

The transition to EVs represents a pivotal moment in the automotive industry's history. The revolutionary transition demands foresight, adaptability, and collective effort. Embracing diversity, bolstering resilience, and committing to sustainable practices by all stakeholders worldwide will bring about a future where mobility is accessible to all, and the earth’s ecosystems thrive in harmony with human innovation.

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