Implications of Global Electric Vehicle Adoption Targets for Mexico Light Duty Auto Industry

Preliminary Research Report

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Acronyms and Abbreviations

AMIA - Asociación Mexicana de la Industria Automotriz (Mexican Association of the Automotive Industry)
BEV - Battery Electric Vehicle
BMW - Bayerische Motoren Werke AG
BTM - Bilateral Trade Matrix
CAFÉ - Corporate Average Fuel Economy
CATL - Contemporary Amperex Technology Co., Limited
CIMT - Canadian International Merchandise Trade
CoMIT - Comprehensive Modal Emissions Model for Inspecting Trends
DE – Domestic Exports
DS – Domestic Supply
EV - Electric Vehicle
EU - European Union
FCA - Fiat Chrysler Automobiles
FDI - Foreign Direct Investment
FS – Foreign Supply
GEC – Global Energy and Climate Model
GHG - Greenhouse Gas
GM - General Motors
GTAP - Global Trade Analysis Project
GTEM - Global Trade and Environment Model
GWh -Gigawatt-hour
ICEV - Internal Combustion Engine Vehicle
ICCT - International Council on Clean Transportation
IEA - International Energy Agency
IHS - IHS Markit
INEGI – Instituto Nacional de Estadística y Geografía [National Institute for Geography and Statistics]
ISO - International Organization for Standardization
ITF - International Transport Forum
JAC - Anhui Jianghuai Automobile Co., Ltd.
KIA - Kia Motors Corporation
kWh - Kilowatt-hour
LDV - Light Duty Vehicle
LMICs – Lower- and Middle-Income Countries
MoMo - IEA Mobility Model
MONET - MOdel for iNternational Ev Trade
NEMS - National Electric Mobility Strategy
NAFTA - North American Free Trade Agreement
OEM - Original Equipment Manufacturer
PHEV - Plug-in Hybrid Electric Vehicle
RE – Re-exports

SUV – Sports Utility Vehicle
UAE – United Arab Emirates
UK – United Kingdom
UN - United Nations
UNSD - United Nations Statistics Division
UMSCA - United States-Mexico-Canada Agreement
US - United States
USITC - United States International Trade Commission
USMCA - United States-Mexico-Canada Agreement
VW – Volkswagen
WTO - World Trade Organization
ZEVs - Zero-Emission Vehicles

Background and Motivation

Roadmaps to meet greenhouse gas (GHG) emissions reduction targets in industrialized nations increasingly include extensive vehicle electrification as an efficient, clean, and comfortable transportation decarbonization solution, particularly for the light-duty sector.

For vehicle producers around the world, this shift represents both, a challenge to adapt their operations to meet consumer demands, and an extraordinary opportunity to rethink business as usual and restructure production and supply chains to become leaders in the development and sales of clean transportation technology.

The Mexican auto industry is the fifth largest light duty vehicle (LDV) exporter in the world, the single largest foreign supplier to the US[1] with close to 15% of the market, and a significant contributor to the Canadian, European, and South American markets as shown in Figure 1.

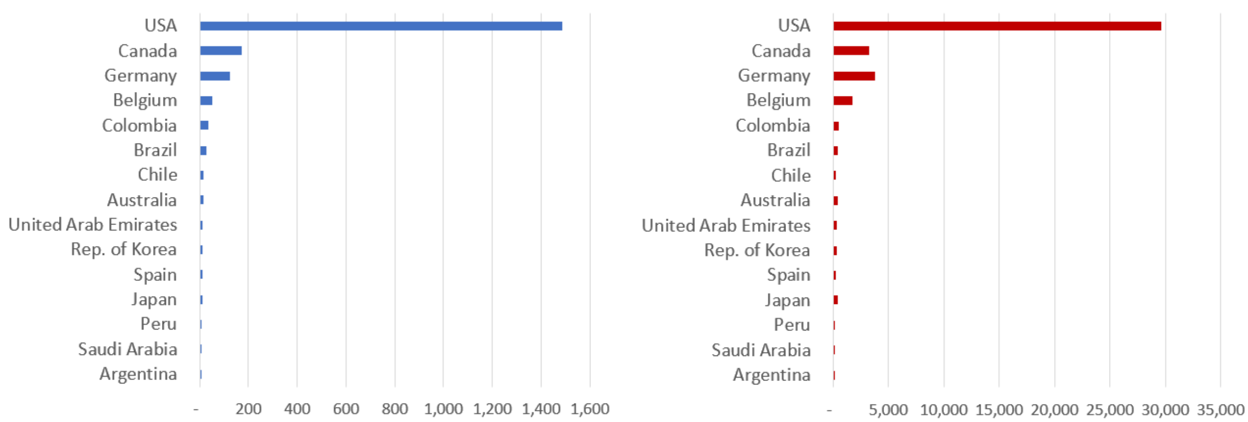

Figure 1: *Vehicle Exports, Mexico 2021.* ***Left:*** *Unit Exports (in thousands)*[10], ***Right****: Exports Value ($ in Millions)*[2]

Representing close to 1 million direct jobs and contributing roughly 4% of the gross domestic product with US $77 billion revenue surplus in 2021[2], as depicted in Figure 2https://www.amia.com.mx/, it is hard to overstate how critical the Mexican automotive industry has become for the national economy in the past 15 years.

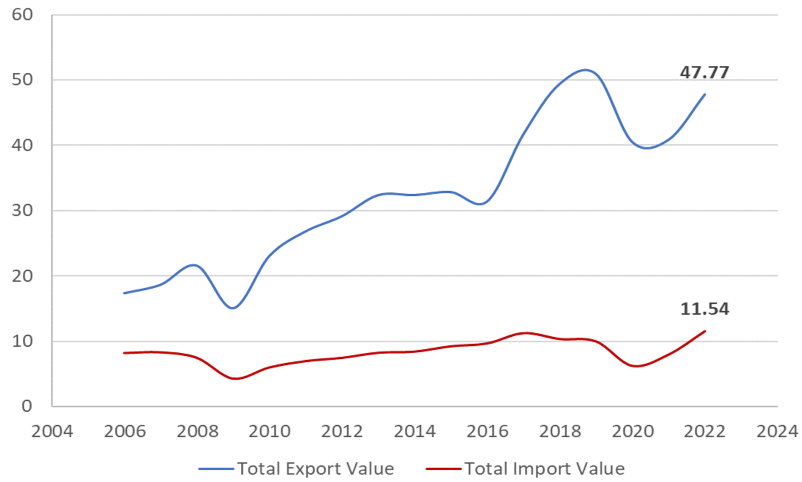

Figure 2: *Mexico International Vehicle Commerce: Net Monthly Cash Flow ($ in Billions)*

The remarkable revenue surplus that Mexico has experienced from the automotive industry can be explained by a national and regional industrial policy that has geared automotive production towards serving the export market rather than the internal demand[3]. As a result of this strategy, production tagged for export has risen from 70% in 2005 to a historical maximum of 91% in 2021[1].

The Mexican auto industry is currently grappling with a significant paradigm shift, as the world moves from traditional internal combustion engine vehicles to electric vehicles. This global transition has the potential to impact the industry in ways that are both promising and challenging. On one hand, there is a growing demand for light duty electric vehicles in the global market, which presents a unique opportunity for Mexico's auto industry to expand and thrive. On the other hand, the shift towards electric vehicles is an inevitability, and companies that fail to keep up may lose market share.

The main export markets for the Mexican auto industry, namely the United States and Canada, are expected to shift to 50% electric vehicles within the next 10 years[4], while other developing markets have already committed to a complete transition to electric vehicles within 15 to 20 years. The global south market, which currently does not constitute a large part of the market share, is expected to grow both in total light-duty sales and in the share of electric vehicles in the coming years. Given the importance of these markets for the Mexican auto industry, it is imperative that industry leaders remain mindful of the potential impact of global market trends and the impact of trends policies on the potential changes. This paper takes a first thorough analysis of the global transition scenarios and assesses their potential impact on the industry. By doing so, industry leaders can better understand the challenges and opportunities associated with the transition to develop effective policy strategies and growth plans to capitalize on them. Moreover, transitioning to electric vehicles represents a unique opportunity for Mexico to assert its leadership in the auto industry within the regional markets and within the large global companies that are represented in Mexico.

This paper explores the global market demand and supply for internal combustion engine vehicles (ICEV) and electric vehicles (EV) by different global trend scenarios, representing sets of local policies to promote or limit global trends of electric vehicles and the potential impact on the Mexican auto industry.

Mexico auto industry

Mexico's automotive market relies on attracting foreign currency through selling premium vehicles in the export market and supplying the internal market with low-cost imports. This strategy becomes apparent upon comparing Figure 1 and Figure 3, which show the country's 2021 exports and imports, respectively. While unit exports and the total value of exports for each country are highly correlated in Figure 1**,** there is a significant discrepancy between the number of units imported and the full value of imports for each country in Figure 3. This indicates that while Mexico exported close to 2.2 million vehicles in 2021 with a weighted average unit price of approximately US $20,000 and its primary destination being the United States (US), it imported a comparatively small 0.65 million vehicles with a weighted average unit price of close to US $13,000 with the US, India, China, and Japan as the leading sources[5].

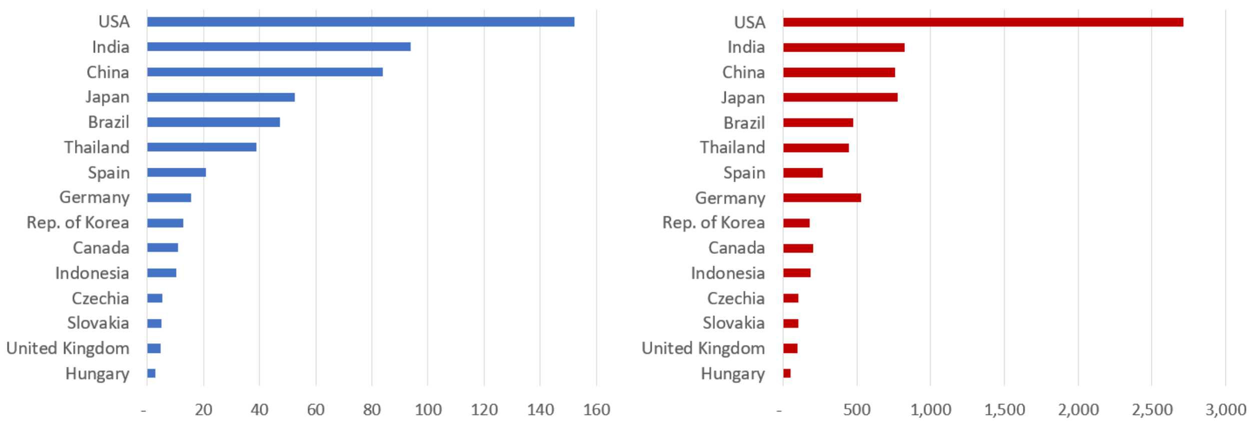

Figure 3: *Vehicle Imports, Mexico 2021.* ***Left:*** *Unit Imports (in thousands);* ***Right****: Imports Value ($ in Millions)* [5]

Additionally, Mexico's automotive industry is the country's most significant source of foreign direct investment (FDI), attracting 20 out of every 100 dollars of FDI in the last five years for an average of close to $5.6 billion a year[1].

Mexico's Position in the Global Automotive Industry: Significance of NAFTA and the Opportunities and Challenges under the USMCA

Mexico's low production costs, robust trade infrastructure, strategic geographic location at the doorstep of one of the most vigorous consumer markets in the world, as well as its membership in a number of trade partnerships, most notoriously the United States-Mexico-Canada Agreement (USMCA), puts the country in a privileged position to leverage the rapid transition nations are undertaking to meet emissions targets, particularly as the US adopts a nationwide goal for EVs to make up 50% of its roughly 17 million yearly vehicle sales by 2030 (White House, 2022).

The USMCA is the 2018 revision, promoted by the Trump administration, of the Clinton era agreement intended to strengthen regional commerce by reducing trade barriers widely known as the North American Free Trade Agreement (NAFTA).

While NAFTA encompassed all economic sectors, one of the most significant outcomes, particularly for Mexico, was that the trilateral enactment of NAFTA institutionalized the long-standing trend of integration of the countries' automotive industries, resulting in cars and car parts being the highest traded commodities, in volume and value, among the three[6].

The original agreement established the rules and mechanisms for automotive trade among the three countries, as broadly depicted in Table 1. Effectively, for Mexico, adherence to NAFTA meant opening its market to its North American counterparts by progressively removing its domestic added value requirements, national rules of origin, and domestic market access requirements. It also meant gradually removing barriers to the import of second-hand vehicles from the US and Canada, removing the country's foreign ownership restrictions, and guaranteeing equal benefits for foreign and domestic producers within its territory[7].

Table 1 Auto Industry Regulatory Mechanisms under NAFTA

Tariff and Non-Tariff Barriers	Vehicle Tariffs
	Vehicle Parts Tariffs
	Regional Content Requirements
	Balance of Trade Requirements
	Import Quotas
	Used Parts Quotas
Rules of Origin	Duty-free Treatment Qualifying Certificate
	Regional Origin Calculation Methods
Corporate Average Fuel Economy (CAFÉ) Standards	OEM Efficiency and Environmental Regulations

The main updates to NAFTA automotive regulations under the USMCA include:

- Gradually increasing the required percentage of North American-made parts in cars from 62.5% to 75% by 2023[8].
- Mandating that automakers manufacture 40% of their vehicles in facilities where workers earn at least $16 an hour[8].
- Strengthening union rights and allowing auto workers in Mexico to form collective bargaining units[8].
- US tariff exemptions on certain Mexican-made vehicles, light trucks, and auto parts from both Mexico and Canada[8].

With rising wages and unionization in Mexican factories and a heightened reliance on more expensive domestic parts, the new trade deal will likely increase production costs for North American automakers, potentially resulting in higher prices passed on to consumers. The deal might also lead to a shift in auto-part production from Mexico and Canada to the US, where most auto manufacturing plants are located, minimizing supply chain delays.

On the other hand, the updated rules of origin could lead to increased collaboration and integration between North American supply chains. In addition, improvements in labor conditions and wages, coupled with US tariff exemptions on certain Mexican-made vehicles, light trucks, and auto parts, could support increased living standards and boost the productivity and efficiency of Mexican auto workers without compromising the market share of Mexican-made vehicles.

The Mexican automotive industry has benefited greatly over the past 25 years due to the implementation of NAFTA. It has allowed the country to attract major automotive firms from Asia, Europe, and North America, resulting in significant growth[9], as described in the previous section. Currently, nearly 90% of the industry's production is destined for exports, with the US accounting for over 70% of the volume of exports. While this has been highly beneficial, it is important to recognize the potential risks associated with a high level of dependency on a single foreign partner, as it may lead to unhealthy market consolidation and pose significant risks to the industry's future growth and sustainability in the event of any changes in the US market or trade policies.

Current Mexican auto industry landscape and near-term plans

As shown in **Figure 4**, Mexico hosts a significant number of original equipment manufacturer (OEM) clustered in the country's northern and central regions. In total, there are 20 LDV assembly plants with 83,967 employees and a total production capacity of 5,056,148 LDVs per year. Also, there are ten motor production facilities with an aggregate capacity of 5,682,180 motors per year and over 11,000 employees, and seven transmission production plants with an aggregate capacity of 2,373,800 transmissions per year and nearly 9,000 employees[1].

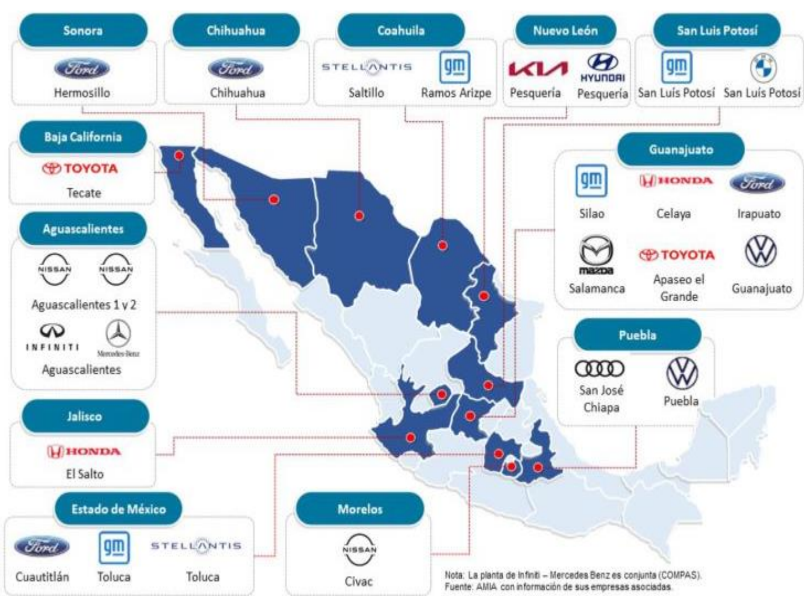

***Figure 4**: OEMs operating in Mexico, 2022. Source: AMIA*

To increase competitiveness and achieve economies of scale, OEMs worldwide have been consolidating into larger automotive groups. This consolidation also allows for the sharing of technology and resources, as well as reduced development costs. In Mexico, there have historically been 15 OEMs producing LDVs, including Audi, BMW, Chrysler, Fiat, Ford Motor, General Motors, Honda, JAC, KIA, Mazda, Mercedes Benz, Nissan, Renault, Toyota, and Volkswagen[10]. However, these companies have been grouped under 11 larger automotive manufacturers that currently operate in the country, as shown in table 2.

Table 2: *Breakdown of automotive manufacturers and their corresponding OEMs. This table provides a list of the major automotive groups with operations in Mexico and all the corresponding brands under their*

Automotive Manufacturer	**Brands**
Stellantis	Chrysler, Fiat, Peugeot, Citroen, DS, Opel, Vauxhall, Jeep, Dodge, Ram, Alfa Romeo, Maserati, Lancia
Ford Motor Company	Ford, Lincoln
General Motors Company	Chevrolet, GMC, Buick, Cadillac
Honda Motor Company	Honda, Acura
Hyundai Motor Group	Hyundai, KIA, Genesis
JAC Motors	JAC
Mazda Motor Corporation	Mazda
Nissan Motor Company	Nissan, Infiniti
Renault Group	Renault
Toyota Motor Corporation	Toyota, Lexus
Volkswagen Group	Volkswagen, Audi, Porsche, Bentley, Lamborghini, Bugatti
Daimler AG	Mercedes Benz

Overall, the automotive industry in Mexico has shown growth in vehicle production volumes since 2010, with a peak in 2017. However, there has been significant variation in production volumes among the different OEMs over time. Some OEMs, such as Nissan and General Motors, have consistently produced high volumes of vehicles in Mexico, while others, such as Renault and Fiat, ceased production in 2011 and 2019, respectively. Conversely, Audi, BMW, JAC, KIA, Mazda, and Mercedes launched production in the country during the same period[10]. Figure 5 provides an overview of the different OEMs operating in the country and the evolution of their share of total domestic production.

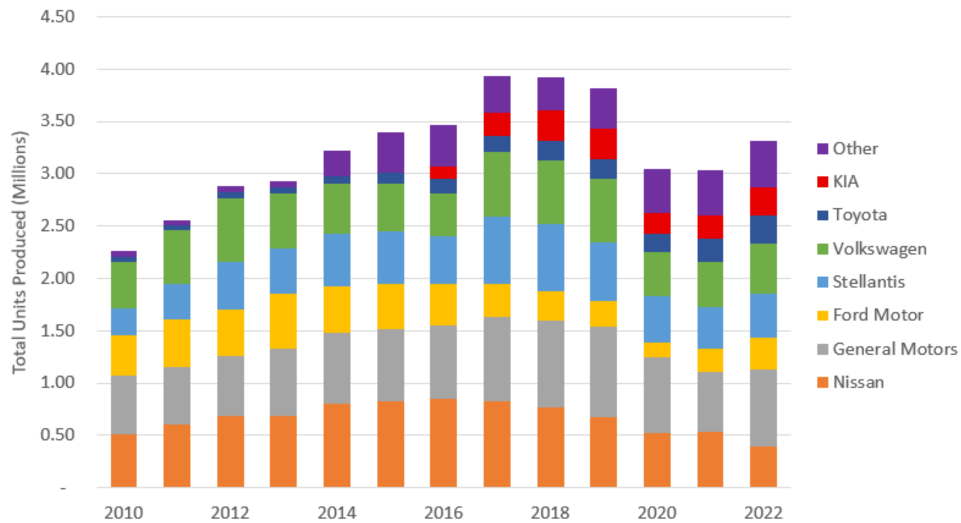

Figure 5: *Yearly production of OEMs operating in Mexico, 2010-2022*

** "Other" category compiles OEMs with less than 5% participation in total production. This category includes Mazda, Honda, Mercedes Benz, BMW, and JAC. Some of the OEMs in the category have only recently launched production in the country but have increasingly gained in share of total production. Namely, Mercedes Benz has gained 3% over the past 5*

Figure 6 provides an in-depth look into the performance and competitiveness of Mexico's automotive industry. It shows the total LDV production for 2022 by the major OEMs operating in the country, highlighting their relative shares of the global and regional supply. On average, Mexico supplies close to 10% of global manufacturing across all major OEMs. However, when examining the regional supply figures, it becomes clear that the OEMs have made significant investments in developing capacity in Mexico. For example, nearly 50% of Nissan's total production in the region, 25% of GM and Stellantis, and 75% of VW's production in the region come from Mexico[10].

As the trend towards electric vehicles continues, it is becoming increasingly important for OEMs in Mexico to consider transitioning their production lines to accommodate EV production. This is especially relevant for those OEMs that rely on the US market, one of the largest consumers of LDVs in the world, and a market that is expected to see continued growth in EV adoption. In this context, OEMs with a significant production share in Mexico, such as Nissan and Volkswagen, may have an advantage in transitioning to EV production due to their existing manufacturing infrastructure and expertise, as well as their ability to use the significant size of their operations to influence strategic decisions within their companies.

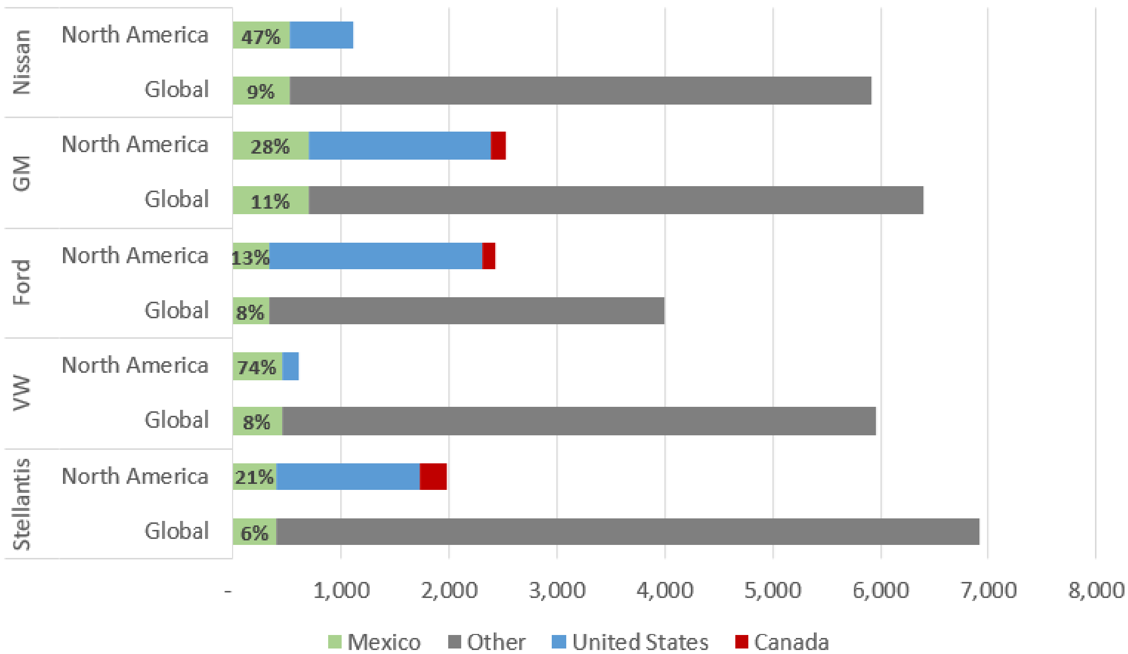

Figure 6: *Mexico's 2022 total LDV production by major OEM operating in the country (in thousands), and the share of global and regional production it represents.*

At the moment, as depicted in Table 3, only a handful of established Mexican OEMs have started large-scale production of EVs, with only one fully Battery Electric Vehicle (BEV) model, namely the Mustang Mach-E, and three Plug-in Hybrid Electric Vehicles (PHEVs) including the BMW 3 series, and the Audi Q5 and Q5 Sportback[10]. These luxury sports utility vehicles (SUV) are intended for sale in the US market. As consumer demand for EVs continues to rise, OEMs without a strong EV portfolio may struggle to compete with their rivals and may find themselves at a disadvantage in the US and other major markets.

Table 3: *EV and PHEV models produced in Mexico in 2022*

Propulsion Technology	OEM	Brand and Model	Units Produced
BEV	Ford	Mustang Mach-E	103,601
PHEV	BMW	3 Series - G20	6,633
	Volkswagen	Audi Q5 Sportback	7,365
		Audi Q5	18,242

Like Figure 6, Figure 7 sheds light on the EV production landscape in Mexico in 2022. It provides a breakdown of the total EV production by major OEMs with production capacity in the country, indicating their relative share of global and regional supply. Of note, Ford emerges as a major player in Mexico's EV market. While it has the least relative share of LDV production in the country, it produces 61% of its total global production of nearly 160,000 units in Mexico, the most out of any OEM in the country. This amounts to a large regional share of 76%. Additionally, the data shows that although the total regional PHEV production of VW is relatively small, with close to 25,000 units, 100% of the North American production is done in Mexico[10]. This could indicate that VW has confidence in the country's automotive environment and institutions, as well as in the solidity of its trade relationships. Figure 7 underscores the growing importance of Mexico as an EV production hub and demonstrates that major OEMs are investing in the country to leverage its advantages, including its proximity to the US market and access to skilled labor.

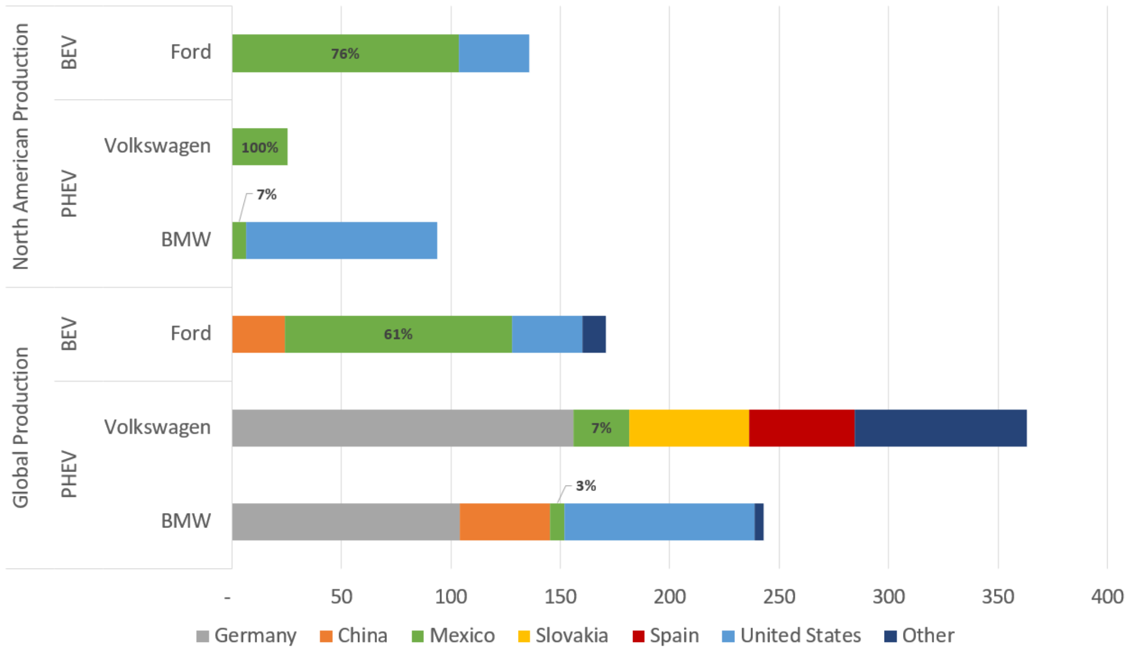

Figure 7: *Mexico's 2022 total BEV and PHEV production by OEM with production capacity in the country (in thousands), and the share of global and regional production it represents.*

Overall, close to 77% of total Mexican LDV exports are destined to supply the US market, as was established in Figure 1, with around 8% going to Canada and 6% to Germany. While the prioritization of supply to the US holds true when broken down by OEM, some interesting patterns arise when analyzing the exports distribution maps of Figure 8:

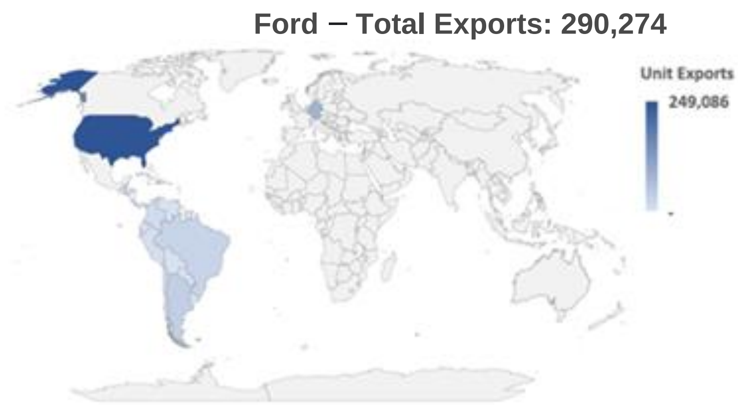

***Figure 8**: Maps showing the number of vehicles exported from Mexico in 2022*

The Mexican operations of General Motors, Ford, and Stellantis are geared almost entirely to serve US consumption as they allocate over 90% of their respective productions to the export market, supplying the US market with close to 85% of their total exports. The remaining 15% is distributed generally among Canada, South American, and Caribbean countries, with Brazil, Argentina, Colombia, Chile, and Puerto Rico taking the most significant shares and Middle Eastern countries with Saudi Arabia and the United Arab Emirates (UAE) in the forefront[10].

On the other hand, Nissan and Volkswagen follow different strategies. Although these OEMs allocate a smaller share of their production to the export market, approximately 50%, they also export only 60% of that production to the US market. The remaining 40% is distributed among Canada, South America, and, in the case of Nissan, a small share to countries in Western Africa, and, in the case of VW through its Audi brand, a small share to countries in Southern Asia and Oceania[10].

It is also worth noting that Toyota and KIA, while not depicted in Figure 8, are significant players in Mexican vehicle exports ranking 5th and 7th place respectively by trade volume. Toyota exports 95% of its Mexican production destined exclusively to the US and Canada. KIA, on the other hand exports 75% of its production with 80% of that destined for the US, 8% for Canada and the rest to South America[10]. As of 2022, 95 different vehicle models were produced out of which only Ford's Mustang Mach-E and JAC's E suite were fully electric, representing only 2.4% of production.

As shown in Table 4, OEMs operating in the country have already begun announcing significant investments to update their existing material and human infrastructure to accommodate the transition and position themselves as early suppliers to the North American market. Most notably, in 2019, Ford spearheaded the initiative and launched the production of its first fully electric light-duty vehicle, the Mustang Mach-E, reaching 65,000 units produced in 2021 with plans to expand to 200,000 units by 2023[11].

Table 4 OEM Investment Announcements in Mexico

OEM	Announcement	Country	Investment Amount	Target Year
Tesla	Opening new Gigafactory in northern Mexican state of Nuevo Leon[12]	United States	**$5,000 M**	N/A
Jetour	Building plant to manufacture electric and gasoline-powered cars for the North American market[13]	China	**$3,000 M**	2024
GM	Facility will begin producing at least one EV beginning in 2023. Electronic components such as electric motors and a paint shop[14].	United States	$1,000 **M**	2023

OEM	Announcement	Country	Investment Amount	Target Year
BMW	500 M towards a battery production plant in San Luis Potosí. Rest will be destined to reconfigure production lines to accommodate EV manufacturing[15].	Germany	$864 **M**	2027
Giant Motors Latinoamerica	Adjusting existing manufacturing plant for 19 different JAC models, including 6 EV models[16]	Mexico/China	$200 **M**	2022
Link EV Electric Vehicles	Nominal capacity of 1,200 units of minibuses, cargo and passenger vans as well as urban buses[17]	United States	$ 265 **M**	2022
Zacua	Strengthen operations and supply chain[18]	Mexico	$ 20 **M**	2023

In addition to vehicle production announcements by OEMs, companies from around the world providing EV ancillary products and services such as battery manufacturing or lithium mining are also announcing their investments in Mexico to support and capitalize on the development of the industry.

Table 5 Additional EV Infrastructure and Support Investment Announcements in Mexico

OEM	Announcement	Country	Investment Amount	Target Year
CATL	Factory capable of producing as much as 80 gigawatt-hours of batteries a year[19]	China	**$ 5,000 M**	On Hold
Ganfeng	Lithium extraction in Sonora. Establish a North American supply chain for battery raw materials[20][21].	China	**$ 420 M**	On Hold
Cenntro Automotive México	Produce lithium-ion batteries in Nuevo León and distribute electric vehicles across the country[22]	US/ Mexico	**$ 200 M**	2023
BMW/Evergo	To build more than 4,000 public charging stations for electric vehicles in the country over the next five years[23].	Germany/ Dominican Rep.	**$ 200 M**	2023
Posco International	Construction of a plant in Mexico to manufacture 1.5 million EV motor	South Korea	**$ 123.2 M**	2023

OEM	Announcement	Country	Investment Amount	Target Year
	cores per year and enter the expanding North American EV market[24].			
LG Magna e-Powertrain	Build an electric-vehicle parts factory in Mexico[25]	Japan/Canada	**$ 100 M**	2023

Additionally, Mexico expects to increase the share of EVs sold internally by enacting its National Electric Mobility Strategy (NEMS) in late 2022. NEMS is a policy instrument aimed at mitigating transportation emissions and guiding electric mobility development, outlining the country's progressive light-duty EV sales targets designed to reach 100% of total vehicle sales by 2050[26].

Understanding the current global supply and demand of LDVs and the impact of international agreements and EV adoption policies, especially in Mexico's largest export markets, are critical to estimate the impact of producing EVs and related products on Mexico's economy, environment, labor, and workforce education needs.

Our research aims to provide information and tools to help design public policy to support the country's capacity to respond to the global shift to EVs and leverage its position for success.
To do this, we developed a global LDV supply model capable of analyzing different propulsion technologies and performing scenario analyses of future demand changes for Mexico, the North American region, and the world.

ICEV global market change

ICEV have been the dominant mode of transportation for decades, but the automotive industry is undergoing a major transformation towards EVs due to concerns over climate change and pollution. The number of EVs on the road globally is expected to reach 145 million by 2030, up from 11 million in 2020 and will result in approximately 60% of new LDV sales to be electric by 2040 (IEA, 2022). This implies that 30% share of the global passenger vehicle fleet in 2040 will be replaced by electric LDVs.

Year 2021, saw doubling in the global spending in subsidies and incentives to nearly USD 30 billion along with governments around the world implementing stricter policies to encourage the adoption of electric vehicles, and phasing out fossil fuel vehicles to meet their net zero target goals. United States has set a new ambition of achieving 50% of all new LDV sales to be electric by 2030. Canada and Chile have announcements to achieve 100% Zero emission LDV sales by 2035. Further, increased stringency in CAFÉ and GHG vehicle emission standard by USA and European union are pushing major automakers to switch to accelerated electrification and brace for a fully electric future. Table 6 summarizes the announcements made by major automakers in their stead to pursue electrification by developing new products as well as converting existing manufacturing capacity in different global markets (IEA, 2022). As a result of automakers' commitment to electrify, the LDV market has seen a fivefold increase in the available electric LDV models from 79 to a staggering 450 by the end of 2021.

Table 6: Major Automakers plan to shift away from ICEVs.

Automaker	**Target year**	**Announcement**
Toyota	2030	3.5 million annual sales of electric cars
Volkswagen	2030 2040	All electric sale in Europe (70%) China (50%) and US (50%) 100% electric sales globally
Lexus	2035	100% electric sales globally
Ford	2030	50% electric sales globally
Volvo	2030	Fully electric
BMW	2030	50% electric sales globally
GM	2040	Be Carbon neutral
Stellantis	2030	100% of European and 50% of US sales be electric
Hyundai	2035	End ICEV sales in Europe

ICEV still have an advantage of a lower price compared to EVs. Except China, electric cars are more expensive option compared to ICEV. The average global BEV price was just under USD 50,000 in 2021, and over USD 57,000 for the average PHEV (IEA, 2022). In China, average cost of BEV is about USD 27,000 in 2021, and USD 40,000 for a PHEV due to domination of smaller car, lower production cost for EVs and domestic battery supply. With increasing driving range and decreasing prices in future, owning, and operating an EV will become outright cheaper in the future compared to ICEVs.

As EVs become more mainstream, the demand for ICE vehicles is likely to decline, and this could lead to a decrease in the production and sale of ICE vehicles. This will be more pronounced in developed countries of Global North like the United States, Canada, Japan, and several countries in Europe, car ownership rates have been declining or remaining relatively flat over the past decade. This trend can be attributed to several factors, including changing attitudes towards car ownership, urbanization, the availability of public transit, and the rise of alternative mobility services like ride-hailing and bike-sharing.

However, it is important to note that ICE vehicles will still exist in the market, especially in developing countries in the Global South where the transition to electric vehicles may take longer due to affordability and infrastructure challenges. In many developing countries, ICE powered car ownership and sales will continue to grow at a rapid pace, driven by factors such as rising incomes, population growth, urbanization, and improving infrastructure. For example, in India, there has been a significant increase in car ownership and sales over the past decade, and these trends are expected to continue in the coming years.

Figure 9 shows the major nations that are pursuing electrification with their share in global electric LDV sales (red line) and the average battery capacity of EVs per vehicle across all LDV segments (blue bars). China leads the way to electrification with 60% share in global EV sales followed by USA that has a little over 10% share. The remarkable thing here is that compared to every other nation, USA has the highest battery capacity requirement for EVs of 82 kWh/veh. It simply means that even with same number of cars being sold USA will require a higher battery size due to domination of larger size cars in new sales. This trend is not going to reverse soon as the global EV sales suggest that bigger SUVs form 47% of new sales around the globe with nation like USA as a major consumer of bigger cars (IEA, 2022). Major OEMs in USA are announcing new product lines featuring electric pick-up trucks with an electric range of up to 500 miles on a single charge. This is going to further drive up the average battery capacity requirements for cars to be sold in USA. This will have a major implication on cars produced in Mexico with USA as its major car market. So we believe that, this gap is not going to close in future but instead is headed to get bigger. Therefore Mexican automotive industry will have to prioritize a strategy for securing enough batteries for catering to its major car make

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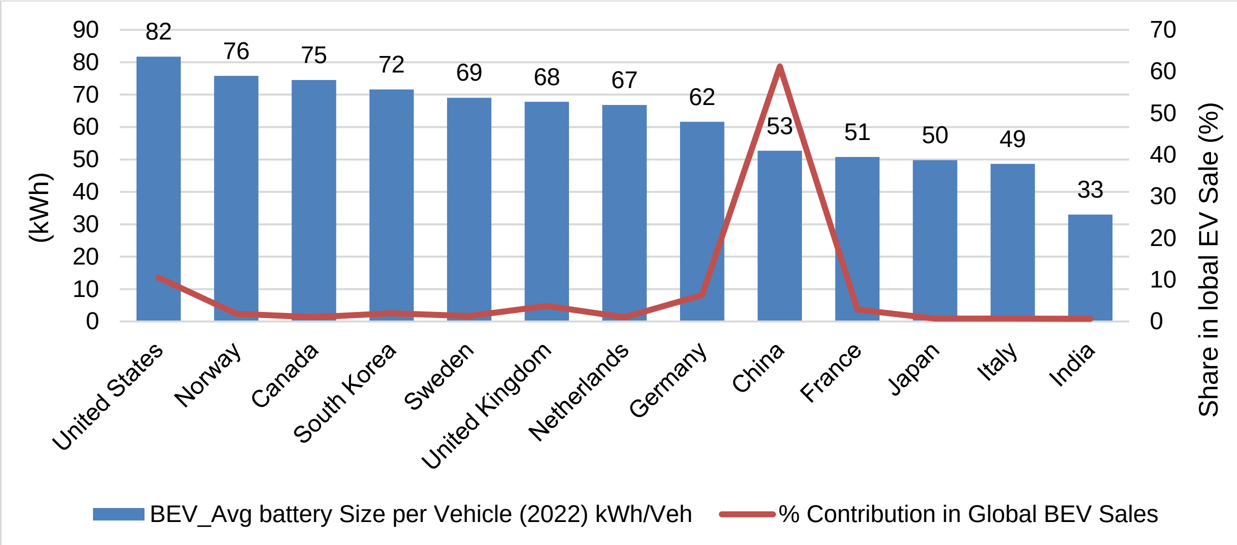

Figure 9*: Average National BEV Battery capacity (kWh) and Share of Global BEV Sales(%)*

Introducing MONET

The MOdel for iNternational Ev Trade (MONET) is a global LDV supply model that has been conceived as a tool to inform policy and industrial strategic planning, allowing for testing, and analyzing different global EV adoption scenarios and the impact of demand adjustments given international EV adoption goals and policies for individual countries or regions over time.

MONET is calibrated using global manufacturing, sales, and trade data from 2013-2021, and uses LDV and EV demand forecasts from various data sources, including a compilation of international government and OEM EV adoption commitments, as input to produce different supply and trade scenarios.

The landscape for energy and transportation systems modeling and EV demand and supply chain modeling is rich and varied. In reviewing the existing literature, we have come across three broad modeling categories that informed our research:

Integrated energy and transportation system models

While models in this category may vary in scope, approach, focus, and geographic coverage, they are all comprehensive models designed to support decision-making and policy analysis toward sustainable energy and transportation policies. They simulate various aspects of the global energy and transportation systems by considering factors such as economic growth, technological change, policy measures, and energy demand to provide projections and insights into the potential impacts of different scenarios. The Global Transportation Roadmap by International Council on Clean Transportation (ICCT)[27], Mobility Model (MoMo) by International Energy Agency (IEA)[28], and the Transport Outlook Project by International Transport Forum (ITF)[29] are a few of the models considered in this category.

Electric Vehicle Supply Chain and Demand Models

These models focus on analyzing the supply and demand of EVs and their related supply chains, projecting future demand for EVs up to 2050 with different levels of regional detail, and focusing on batteries or raw materials for batteries rather than EVs or LDVs. They also consider recycling and second-hand use of batteries scenarios and analyze the supply chain material for lithium to ensure secure, resilient, and sustainable supply chains. The Global Energy and Climate Model (GEC) developed by IEA[30], Comprehensive Modal Emissions Model for Inspecting Trends (CoMIT)[31], and the model described in Dunn et al.[32] are a few of the models considered in this category.

Global Trade Models

These models are used to analyze the impact of trade policies and agreements on the global economy by considering a range of factors like tariffs, exchange rates, and economic and demographic trends. In addition, they evaluate the potential effects of trade policies on various economic outcomes, such as economic growth, employment, and trade flows, and the impacts of trade policies and environmental regulations on the economy and the environment. Some examples of widely used global trade models include the World Trade Organization (WTO) Global Trade Model[33], the Global Trade Analysis Project (GTAP) model[34], and the Global Trade and Environment Model (GTEM)[35].

MONET addresses multiple gaps in the current landscape of global transportation, demand, and trade models. First, while all of the analyzed models focus on the demand side of transportation, MONET also provides insight into the supply side.

Second, MONET is designed for LDV and EV market analysis, while with most of the analyzed models focus on the supply chain for batteries for EVs and/or the raw materials to build them. Third, available literature regarding international EV demand growth, while providing reasonable forecasts for individual countries or regions, fails consistently to account for international trade relationships. Consequently, the regional composition of market supply is not accurately understood and may lead to critical misrepresentations of future market scenarios. To the best of the author's knowledge, this study is the first to account for international trade flows in scenario planning for global EV demand and the necessary supply required to meet it.

Fourth, a big contribution of MONET is the ability to spatially connect supply and demand data for vehicles using the current network of international trade relationships.

Lastly, the realization of accurate LDV trade flows also enables the quantification and tracking of valuable EV components, including lithium-ion battery critical materials, throughout the global supply chain.

Methods

This research develops a model that allows testing and analyzing different global EV adoption scenarios over time and the impact of demand increases for individual countries or regions. To create this model, significant harmonization across available datasets is needed to merge them and create a unified global production and sales dataset. Aggregate production and sales values for 65 countries and aggregate regions (henceforth *countries*) and periods of interest are extracted from the resulting dataset, combined with the corresponding global trade data in a bilateral trade matrix (BTM), and calibrated using the RAS matrix balancing algorithm[36] to estimate trade volumes, regions of origin, regions of destination, and the relationship between global demand and the required supply of vehicles. A new matrix is then created containing the ratios of each element in the BTM to its corresponding regional sales, serving as a tool to calculate required regional supply adjustments in response to variable global demand inputs based on base year market conditions.

Finally, this tool allows us to create a scenario family that accounts for international agreements and EV adoption policies and measures, adjust market assumptions, and focus on different regions and trade interdependencies. Figure 10 further illustrates the modeling method.

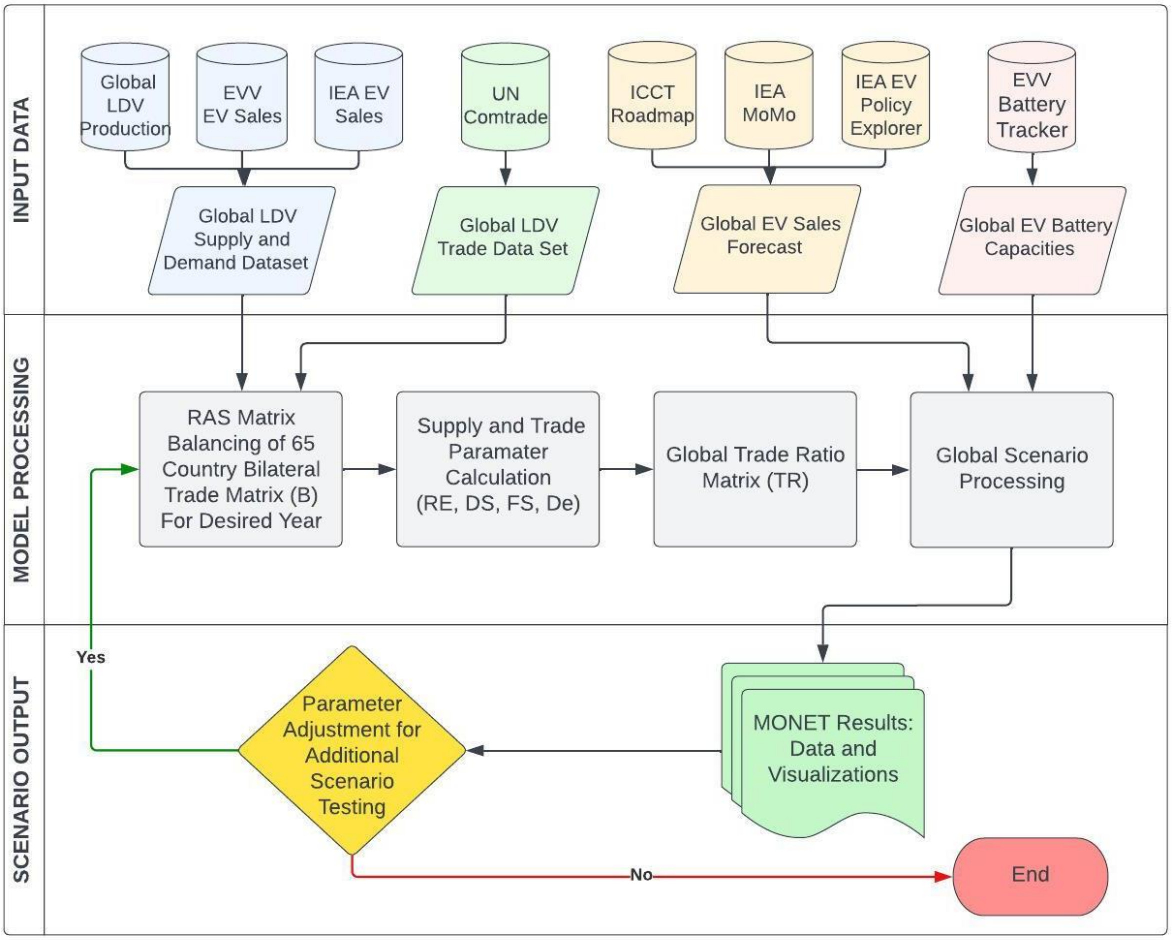

Figure 10: *MONET Operation Flow diagram*

LDV Production and Sales Data Set

Input Data Sets

1. **Global Production data**[37]-[1]
   Contains data on worldwide LDV production from 2001 - 2023, including annual vehicle, engine, and powertrain production per country, and detailed technical information about vehicle models produced such as battery capacity and engine power output.
2. **IEA EV Sales and Total Market Share data**[4]**:**
   Includes annual EV, PHEV, and FCEV units sales per country from 2013 - 2022 broken down by make, model, and propulsion.
3. **EV Volumes: EV Sales data**[38]**:**
   Includes annual EV, PHEV, and FCEV unit sales from 2011 - 2020 in the 30 major country markets, representing around 80% of total global sales. Also includes 4 aggregated major

[1] https://automotive.influencemap.org/#production-data and additional extrapolation by the authors

regions: World, EU, Other EU, and Rest of the World. Particularly interesting from this data set is the percent different EV sales represent out of total country LDV sales. This information is helpful to calculate ICE vehicle sales in different markets.

Final Data Set Outline

After initial exploration of the type and variety of data contained in the three datasets, as well as significant harmonization across dataset labeling, the final merged LDV Production and Sales dataset (henceforth Supply data set) is comprised of the following variables:

1. **Year:** Year of sale or production of vehicles of interest.
2. **Region:** Broad economic and geographic regions through which countries' vehicle activity is grouped and analyzed. These include Europe, China, Japan/Korea, Middle East/Africa, North America, South America, and South Asia.
3. **ISO:** International Organization for Standardization (ISO) country codes are internationally recognized codes that designate every country with a three-letter combination. Country names are often spelled differently due to varying naming conventions, so ISO codes are an effective way to harmonize across different data sets.
4. **Country:** 65 country names where vehicle activity data is available.
5. **Brand:** Major vehicle brands or their design parent corporation.
6. **Model:** Vehicle models produced and sold worldwide.
7. **Propulsion:** Type of propulsion a vehicle of interest has. The four types of propulsion are ICE, BEV, and PHEV.
8. **Qty:** The number of vehicles produced or sold in a given period of interest.
9. **Type:** A binary variable indicating if an entry is referring to sales or production. ("sales" or "prod")

Table 7 Region and country aggregation in MONET.

Region	Countries included
Greater China	China, Taiwan
Japan/Korea	Japan, South Korea
South Asia	Australia, India, Indonesia, Malaysia, New Zealand, Pakistan, Philippines, Singapore, Thailand, Vietnam, Rest of South Asia/Oceania
Middle East/Africa	Algeria, Egypt, Ethiopia, Iran, Israel, Kenya, Morocco, Nigeria, Saudi Arabia, South Africa, United Arab Emirates, Rest of Middle East/Africa
North America	Canada, Mexico, United States
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Peru, Uruguay, Venezuela, Rest of South America
Europe	Austria, Belgium, Czechia, Denmark, Eastern Europe/Central Asia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Russia, Slovakia, Spain, Sweden, Switzerland, Turkey, United Kingdom, Western Europe non-EU, Rest of European Union (EU)

Global LDV Trade Data Set

Input Data

We used Comtrade[5] to extract the 2019 vehicle import and export volumes for all available countries. Comtrade is a United Nations (UN) repository of official trade statistics collected and submitted by national customs authorities and managed by the United Nations Statistics Division (UNSD). The database contains detailed annual merchandise trade data from over 240 countries and territories.

Additionally, we obtained the 2019 import and export data for North American countries from the Mexican Automotive Industry Association (AMIA)[39] and Mexico's National Institute for Geography and Statistics (INEGI)[10], the United States International Trade Commission (USITC)[40], and the Canadian International Merchandise Trade (CIMT)[41] to validate the accuracy of the volumes provided by Comtrade.

Final Data Set Outline

The final merged Global LDV Trade dataset (henceforth *Trade data set)* is comprised of the following variables:

1. **Source region:** Corresponding to the regions defined in the LDV Production and Sales dataset, these are broad economic and geographic regions under which countries' vehicle exports are aggregated and analyzed. These include Europe, Greater China, Japan/Korea, Middle East/Africa, North America, South America, South Asia, World.
2. **Source country:** Names of countries exporting vehicles.
3. **Source ISO:** ISO country codes for exporting countries.
4. **Target region:** Broad economic and geographic regions importing vehicles. Same regions defined in *Source region variable.*
5. **Target country:** Names of countries importing vehicles.
6. **Target ISO:** ISO country codes for importing countries.
   Qty: The number of vehicles traded from one region or country to another.
7. **Type:** A binary variable indicating if an entry refers to an import or an export.

Global EV Sales Forecast

Input Data Sets and Information

1. **ICCT Roadmap[27] and IEA MoMo[28]:** The data from the ICCT and MoMo consist of future LDV sales projections for the year 2050 for different countries and regions of the world.
2. **IEA Global EV Policy Explorer[42]:** This tool highlights key policies and measures that support the deployment of EVs and zero-emission vehicles (ZEVs) for light and heavy-duty vehicles. It summarizes current measures as well as announced targets and ambitions by region and country.

Final Data Set Outline

Using both data sources, we cross-validated, aggregated, and extracted LDV production projections for the 65 countries previously defined. Then, we used the Global EV Policy Explorer to extract key international policies and measures for EV deployment, including legislation, targets, and ambitions to predict future EV demand. Then, we extracted a vector of EV demand by country by 2035.

Creating a Bilateral Trade Matrix

As illustrated in Figure 11, from the original long form of the trade dataset, we create a two-dimensional square array indicating the exporting regions on the vertical axis, the importing regions on the horizontal axis, and the trade volumes between them. This bilateral trade matrix provides information on the interdependencies between the different countries in the production and consumption of light duty vehicles. Note that the diagonal formed by the convergence of a row and its corresponding country column is necessarily zero, as countries do not trade with themselves.

Imports

Exports

Country	Brazil	Canada	China	Colombia	Eastern Europe/Central	...	Total Exports
Brazil	0	0	13	33,778	0	...	400,538
Canada	458	0	24,930	1,244	82	...	1,777,716
China	16,461	25,005	0	6,398	9,522	...	1,065,446
Colombia	0	0	0	0	0	...	49,788
Eastern Europe/Central	0	0	0	0	0	...	9,062,053
...	...	...	...	...	...		
Total Impots	168,587	1,469,594	1,583,691	187,716	1,047,063		

Figure 11*: Example of 2019 Global BTM. Only a portion of the full matrix is shown here for illustrative purposes.*

Accounting for Yearly Production and Sales discrepancy

From the supply data set, we extract the 2019 production and sales volumes for the 65 countries. We calculate a correction factor (***Cf***) by dividing the aggregate production over the aggregate sales, equation 1, and apply it to the individual production volumes to balance the model input and output volumes.

$$Cf = \frac{\sum P}{\sum S} \qquad (1)$$

Reconciling global trade volumes to fit production and sales data through RAS Matrix Balancing

Global trade data is notorious for presenting conflicting information between the export volumes of a product reported by a country and the volumes reported by the importing counterpart countries[43]. Reports outline the source of this discrepancy citing issues such as:

1. Countries' unwillingness to share trade information.

2. Lack of agency capacity to accurately register trade volumes on either side of the transaction.
3. Conflicting definitions of goods and the appropriate international HS coding across countries.
4. Differences in the use of trade units across countries.
5. Organizational errors in unit conversions.
6. Differences in guidelines used by countries to record and report trade data.
7. Human Error.

To reconcile the data in the bilateral trade matrix, adjusting the volumes of trade for each country to fit the observed sales (***S***) and production (***P***) values for 2019 while also matching the total reported exports volumes (***E***) per country, we employed the RAS matrix balancing algorithm. However, the RAS algorithm can only be used when the row and column totals of the balanced matrix are provided and cannot apply to situations where the matrix totals have to be estimated along with the cell values[44].

To provide the required vector ***E***, we assume that the total exports for each of the 65 defined countries in our trade analysis are equal to the sum of the reported imports received by its 64 counterpart countries. This is because relying on data reported by multiple independent counterpart regions rather than just one trading partner can reduce the risk of inaccuracies or biases in the reported trade data. It also makes it more likely to detect discrepancies in reporting and reduces the risk of political bias or manipulation.

We calculated each country's target import values (***I***) by assuming a perfect balance of goods where all input of goods must be accounted for either in the internal sales of vehicles within a country or as an export to another, as depicted in Figure 12. In other words, we assumed that regions could not have a surplus of vehicles in any of their flows without a corresponding deficit. Thus, we calculated the vector of target imports through ***I = S + E – P*** **(2)**

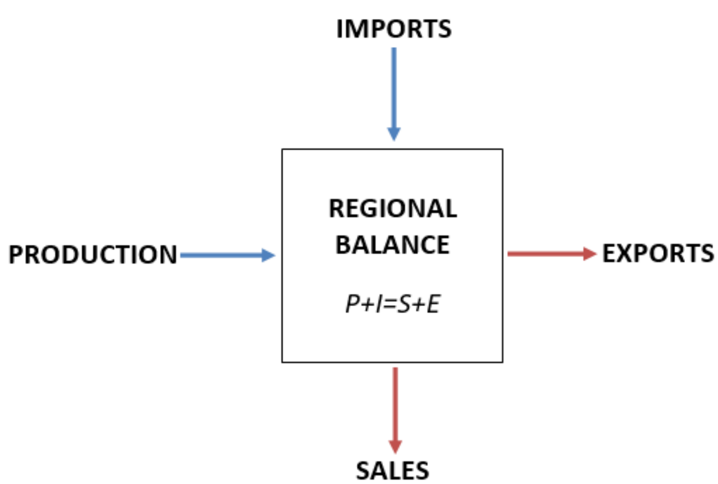

Figure 12: *Diagram illustrating the regional input/output balance of vehicles*

Using the calculated vectors ***E*** and ***I***, we apply RAS to produce a balanced bilateral trade matrix ***B*** where the sum of each row equals its corresponding value in ***E***, and the sum of each column equals its corresponding value in ***I***.

Accounting for Re-exports, Domestic Supply, and Domestic Exports

While re-exporting facilitates the movement of goods and increases access to markets for certain countries, it complicates the tracking of trade flows and may lead to statistical discrepancies in trade data because, typically, when a country re-exports goods that it previously imported, the goods are recorded as exports even though they were not produced domestically[45]. This can distort trade statistics and make it difficult to accurately track the origin and destination of goods in international trade. Especially when different countries have different rules for how re-exports should be classified and reported.

A widely used practice in international trade analysis to resolve this issue is to apply an assumption of proportionality[46] in which imports ***I*** that are destined for re-exports (***RE***) may be estimated by applying the ratio of exports ***E*** over the total inputs to the country (***P+I***). Correspondingly, imports for domestic consumption (**FS**), may be estimated by applying the ratio of internal sales **S** over ***P+I***. The assumption also allows estimating the proportion of domestic production that is destined to supply the local market (**DS**) by applying the ratio of ***S*** over the total ***P+I***, as well as the proportion of domestic production that is destined to be exported (**DE**) by applying the ratio of ***E*** over ***P+I***. Figure 13 illustrates the assumption of proportionality and the resulting calculations for parameters ***RE***, ***DE***, ***DS***, and ***FS***.

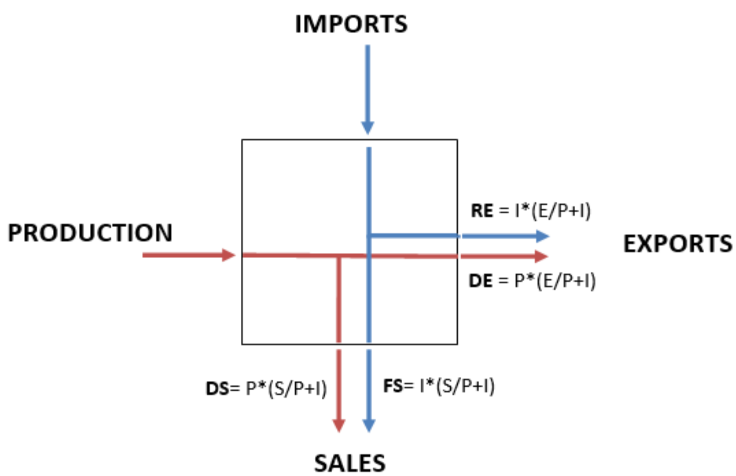

Figure 13: *Diagram illustrating the application of the proportionality assumption.*

To illustrate, suppose that after the balancing procedure, we observe 100 vehicles exported from the Netherlands in a given year, domestic production of 30 vehicles, domestic sales of 50, and total imports to the country of 120. We then assign 120*100/(30+120) = 80 as imports destined for re-exports (RE), 120*50/(30+120) = 30 as imports destined for domestic sales (FS), 30*50/(30+120) = 10 as production for domestic supply (DS), and 30*100/(30+120) = 20 as production destined for foreign markets (DE).

Similarly, we assign values proportionally across associated trade regions. For example, if the Netherlands imported 50 vehicles from the United Kingdom (UK), through the same process we would assign 33 as re-exports and 17 to supply the domestic market.

Applying this process across all regions, we are able to remove re-export values from the original balanced import-export matrix ***B***, effectively obtaining a new matrix ***F*** in which column values now exclusively represent foreign imports destined to be sold in importing countries and row values represent countries' domestic exports. We then assign the amount of regional production destined for domestic supply, i.e., ***DS*** to the diagonal of ***F***. As depicted in Figure 14, where ***P= DE+DS* (3)** and ***S=FS+DS (4)***, with ***DS*** as the diagonal of ***F***, the row sums are exactly equal to the observed ***P***, and the column sums exactly equal to ***S*** as illustrated in Figure 14.

$$\begin{array}{cc} & \begin{array}{ccccc} \text{AUS} & \text{BEL} & \text{CHN} & \text{DEU} & \text{JPN}\end{array} \\ \begin{array}{c}\text{AUS}\\ \text{BEL}\\ \text{CHN}\\ \text{DEU}\\ \text{JPN}\end{array} & \begin{pmatrix} DS & 4 & 0 & 7 & 1\\ 1 & DS & 4 & 4 & 6\\ 3 & 2 & DS & 6 & 6\\ 3 & 2 & 3 & DS & 5\\ 4 & 2 & 3 & 1 & DS\end{pmatrix} \end{array} = \overset{DE}{\begin{bmatrix}12\\15\\17\\13\\10\end{bmatrix}} + \overset{DS}{\begin{bmatrix}3\\4\\5\\6\\7\end{bmatrix}} = \overset{P}{\begin{bmatrix}15\\19\\5\\6\\7\end{bmatrix}}$$

$$\begin{array}{cc} FS & \begin{pmatrix} 11 & 10 & 10 & 18 & 18 \end{pmatrix} \\ & + \\ DS & \begin{pmatrix} 3 & 4 & 5 & 6 & 7 \end{pmatrix} \\ & = \\ S & \begin{pmatrix} 14 & 14 & 15 & 24 & 25 \end{pmatrix} \end{array}$$

Figure 14: *Foreign Supply and Domestic Exports trade matrix F. Values in the matrix do not represent actual data, figure for illustrative purposes only*

F allows us to observe direct relationships between trade partners and, most critically, the effect that changes in demand might induce in production, and vice versa, regionally and globally.

Finally, using element-wise division, we calculate a new matrix ***TR= F ⊘ S (5)*** composed of the ratios of each element of the columns to the corresponding observed value of ***S***. ***TR*** serves as a tool to calculate the required regional production adjustments in response to variable global demand inputs based on current market conditions. This tool allows us to create multiple demand scenarios, adjusting market assumptions and focusing on different regions and trade interdependencies as described in the next section.

Vehicle Production Allocation

The main application of the international LDV balanced trade sales ratios is to estimate the required production of vehicles by each country (supply) given the projected sales by each country (demand). In mathematical terms: the balanced matrix allows us to estimate the production vector using a sales vector. The production allocation of vehicles method follows the formula *Production= f (Sales, Trade Ratios)*, and the following steps:

1. Multiply trade matrix by sales vector: ***TR*S***.
2. The row sum of the new matrix corresponds to the total domestic exports ***DE*** for each country, and the column sums represent the total imports destined for domestic supply ***FS***.
3. Estimate the production of each country as ***P = DS + DE***
4. Estimate total exports by country ***E*** to fit ***P*** through ***E = P + FS - S***
5. Re-balance the new trade matrix using marginal targets ***E*** and ***FS***

Note that the supply requirements for each country will depend on the following factors:

- Demand for vehicles for each country
- International trade relationships between countries

As an example, the future production of vehicles in Mexico will depend not only on the projected domestic sales in Mexico but also on the projected sales of countries that Mexico exports to and production in countries that Mexico imports from.

Scenarios for EV 2035 production allocation

For each demand scenario for EV sales in 2035 by each country, we conduct different production allocation scenarios, with different trade relationship assumptions. The scenarios are:

- **S1 - Constant LDV 2019 trade ratios**: The baseline scenario using the trade relationships derived from the 2019 LDV international market. The main assumption is that EV international trade relationships in 2035 will resemble the 2019 LDV relationships (before the COVID-19 pandemic).
- **S2 - Higher domestic supply**: In this scenario, we assume an increase in the domestic supply for each country, generating consequently less trade among countries. To model this we use the 2019 LDV ***TR*** matrix as a base, then increase the diagonal (domestic supply) by a 40% growth (eg: domestic supply of 10% goes to 14%) and reduce the number of imports in each country accordingly, to maintain the balance.
- **S2b – Higher domestic supply + Free Trade USMCA**: This scenario is similar to S2 in all aspects with the exception that we consider the trade relationship between US, Mexico, and Canada. We allocate the increase in domestic supply of the United States between the partner countries in a relative proportion to their current production. In this scenario, Mexico and Canada supply a big share of the increase in domestic supply of the United States, driven by a decrease in imports coming from other countries.
- **S3 - Global free trade**: This scenario considers an increase in the trade flows among countries. We first identify the top twelve countries that produce EV for exports in 2021 and their relative share of the EV global market. We allocate 50% of future country demand supplied by foreign imports among these 12 specialist countries proportional to their current share of the EV global market exports. Effectively, in this scenario, global trade flows are expanded while concentrating supply within specialist countries. We combine this new ***TR*** matrix with the 2019 LDV relationship, to obtain a projected trade relationship matrix with a global free trade perspective.

Results

2019 Global LDV Trade Relationships

Figure 15 sheds light on the trade relationships obtained from the balanced global LDV market in 2019. We can observe interesting patterns, such as countries with a high share of their demand coming from domestic supply, like Turkey, Slovakia, China, Japan, South Korea, South Africa, United States, Brazil and almost all countries in South Asia. Iran is completely isolated from global trade relationships, with no export or imports. We can also identify exporting focused countries such as Mexico, Germany, Japan and South Korea. All countries with no horizontal box are non-producing countries, that rely totally in imports to meet their LDV demand. Figure 15 trade relationships are the basis for the allocation method to determine the production of future EVs (supply) given the projected demand by country.

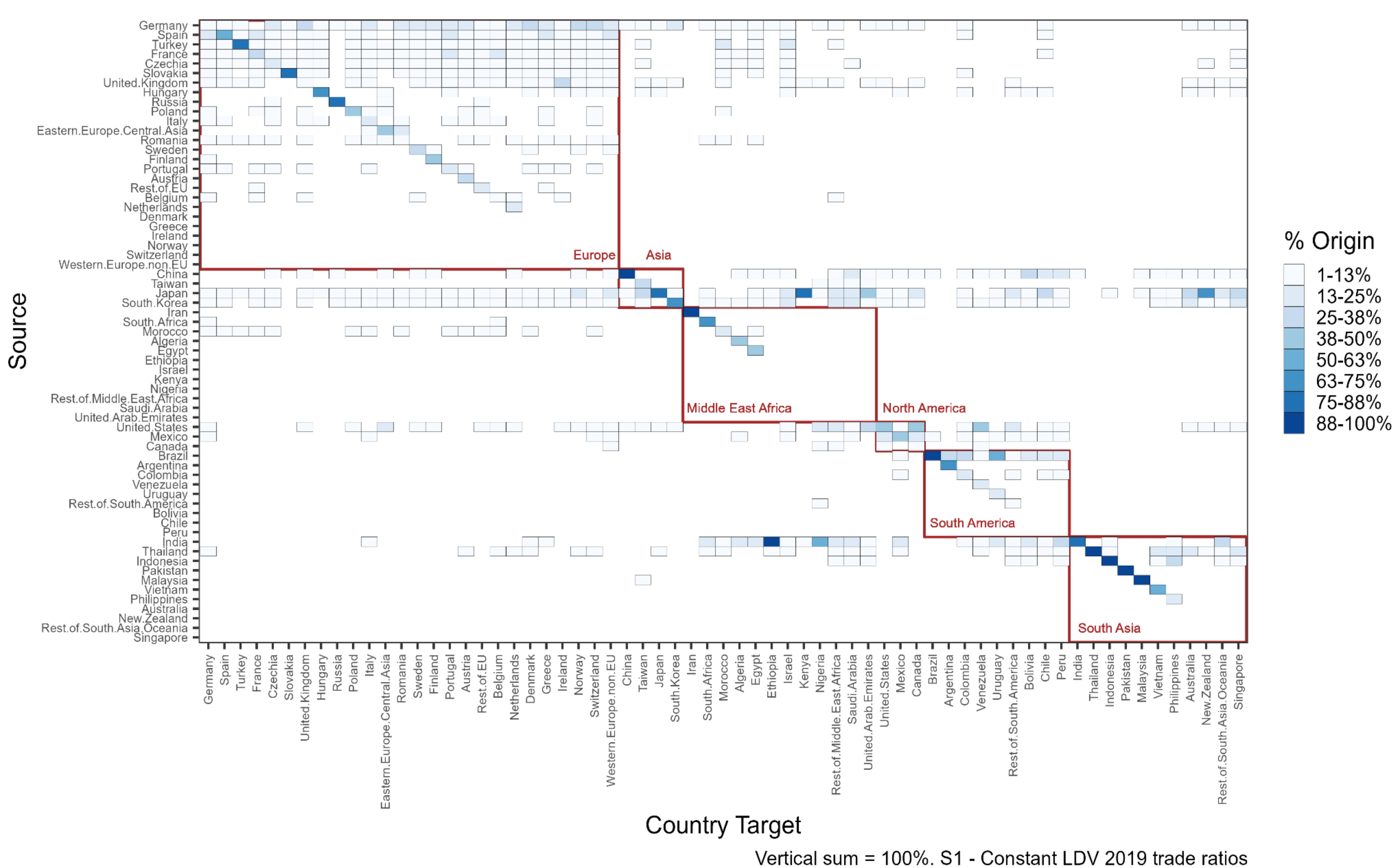

Figure 15: *Trade ratios for LDV 2019 global relationships. Countries are sorted by region and production levels. The vertical sum for each country will equal 100%, which corresponds to the total supply for the domestic demand. Blank cells indicate no trade relation.*

Current North American LDV and EV Supply Relationships

If we analyze the current LDV and EV market in North America we observe interesting patterns. While Mexico currently supplies a significant share of total LDVs to the North American market, and close to 20% of the US market, it supplies a comparatively lower share of the North American EV market with only 6% of the US market (Figure 16). Most of the 2021 EV demand in US is being supply internally and by Japan/Korea. We can also observe that currently most EV production from Mexico goes to Europe, and an important share of US EV production goes to supply China. We expect the emerging relationships in the EV market to evolve and resemble the current more mature LDV global market.

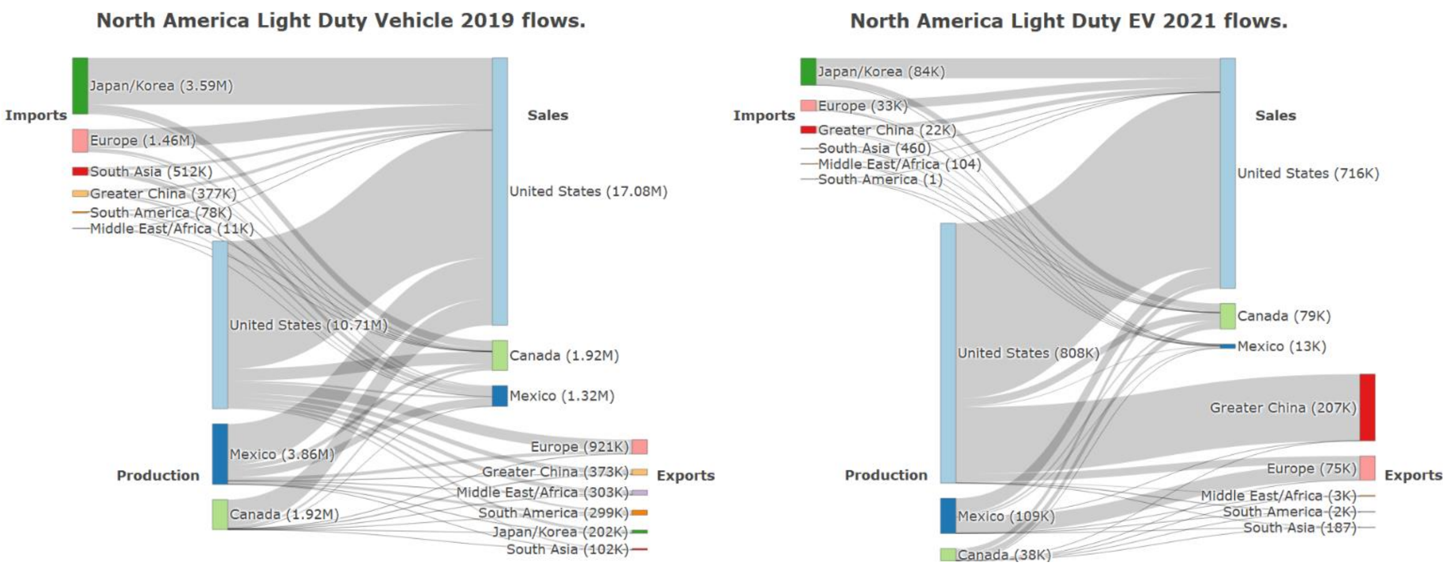

***Figure 16**: 2019 LDV Supply Dynamic in North America (left) and 2021 Light-duty EV Supply Dynamic in North America (right).*

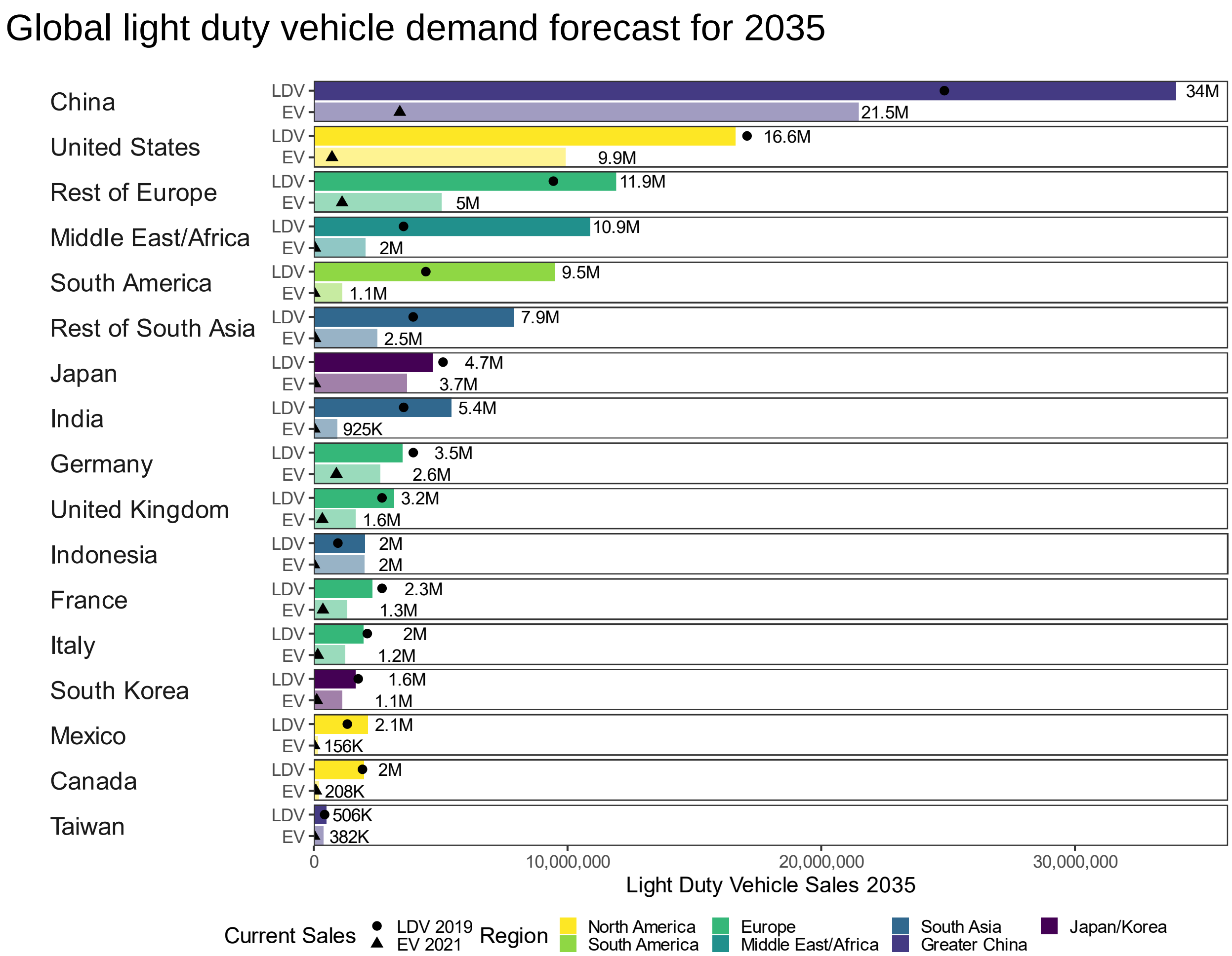

Figure **17** shows the projected demand for LDV and EV in 2035, along with the current sales and percentage growth for the LDV market per country. We observe that China has a projected demand for 34 million vehicles, from which 21.5 million are electric. United States has a projected demand for 16.6 million LDV, with almost 10 million EV. Other countries with considerable projected EV demands are Japan (3.7M) and countries in in the EU, including Germany, France, UK and Italy. A common pattern in countries with high EV projected sales is that currently (in 2021) they have a low EV demand, so they are expecting to transform their market in 15 years. For example, US current demand for EV is around 700 thousand vehicles, so it will need to scale around 14x times to reach the forecasted 2035 demand.

The global LDV growth between 2019 and 2035 is 34%. The majority of the LDV growth is concentrated in emerging markets, such as Middle East/Africa (208%), South Asia (81%), and South America (115%). More mature markets such as US (-3%), Japan (-8%), South Korea (-6%), Germany (-11%) and Italy (-7%) will reduce their LDV demand. As EV demand is driven by an increase in LDV demand and an increase in EV share, for the mature markets it will come entirely from an industry shift.

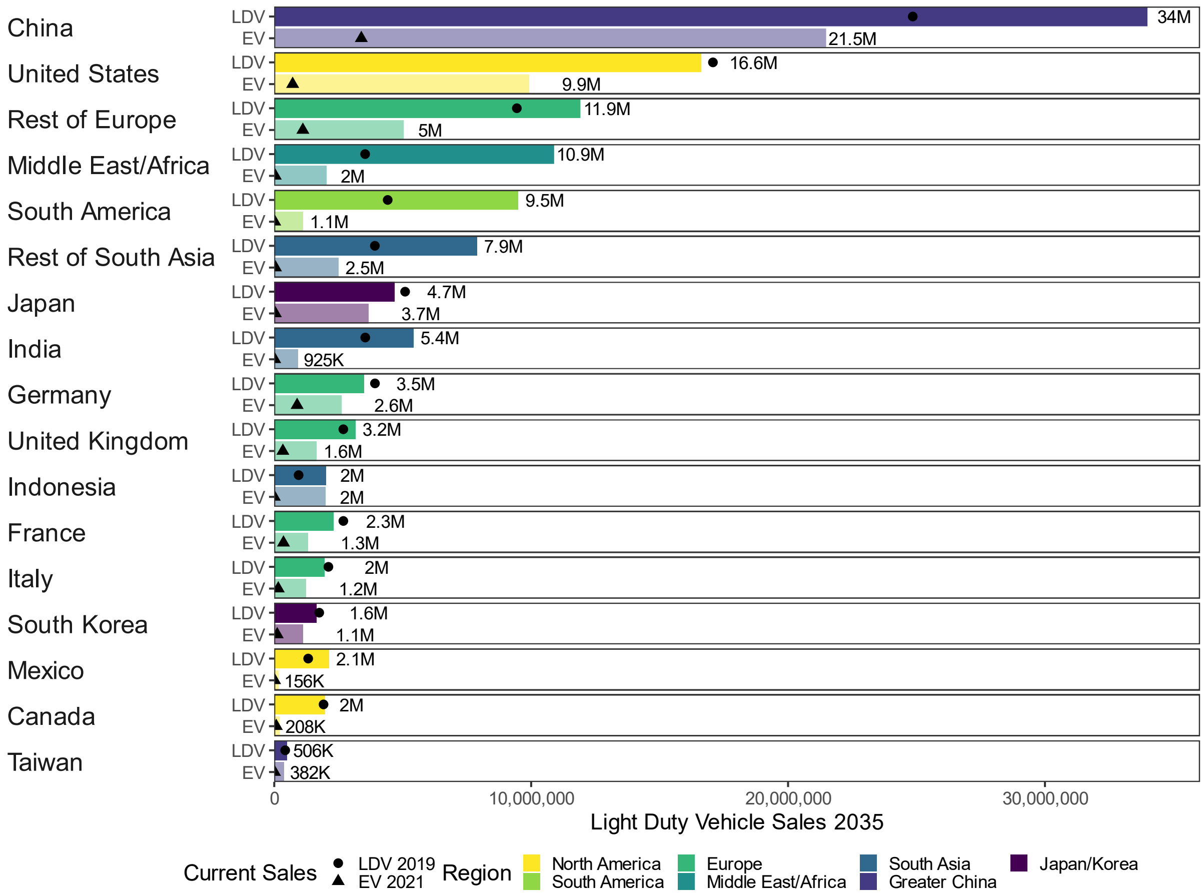

Figure 17*: Projected demand for light duty vehicles in 2035. Points mark current sales for LDV (2019) and EV (2021). Labels indicate 2035 sales.*

EV Production Results - Scenario 1

Using the projected EV sales for 2035 (

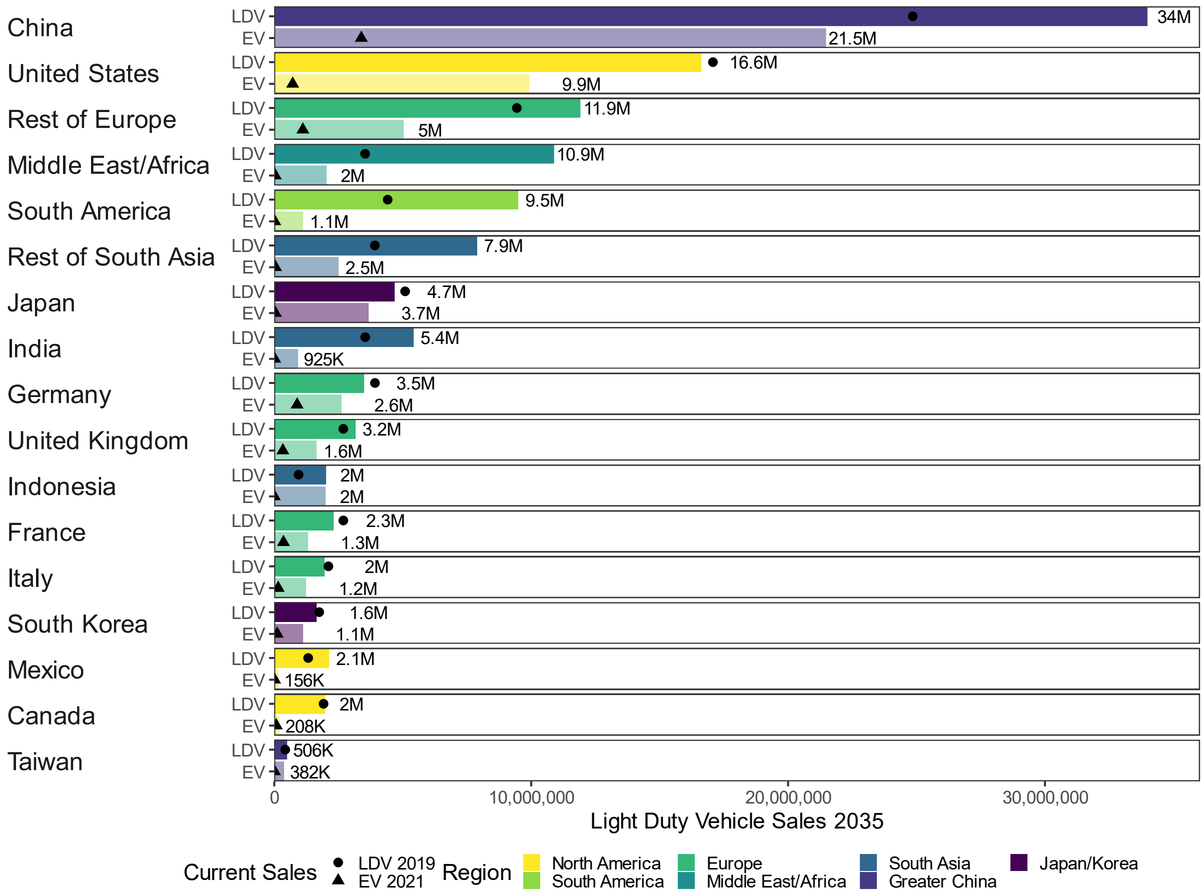

Figure **17**) and the global trade ratios (Figure 15) we can estimate the future production of EV by country (Figure 18). We observe that the dominant producer for EVs will be China, mostly driven by their internal demand and the assumption that their domestic supply share will remain constant. US production is mostly for domestic supply. Japan production is divided equally for internal demand and exports. Production from Germany and Mexico are almost entirely for exports.

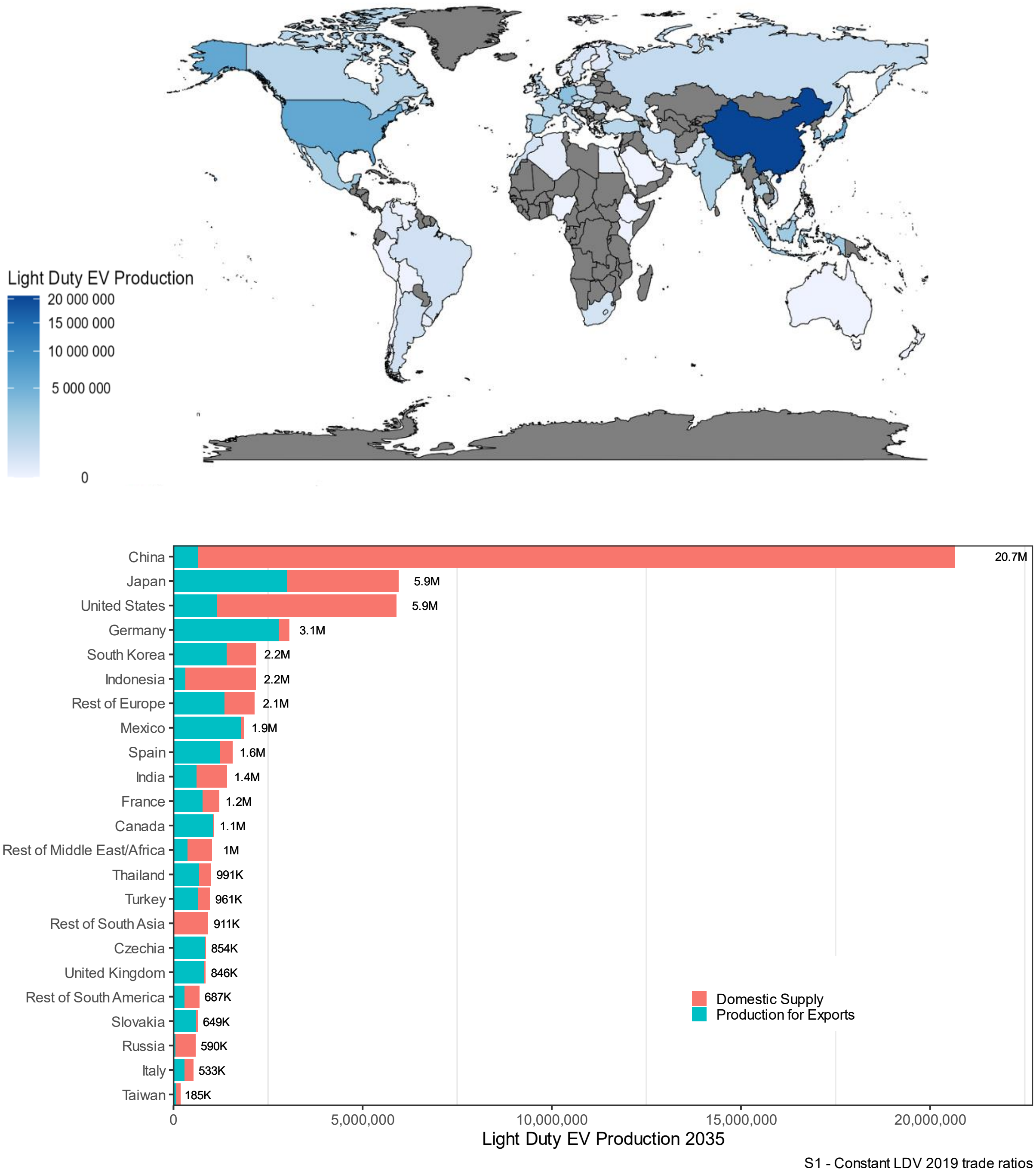

Figure 18: *Projected light duty EV production for 2035 - Scenario 1. In the map, blue saturation indicates higher production. Countries in grey are not modeled explicitly inside MONET, but considered as aggregated regions, due to their low volumes of LDV trade in 2019. The bar graph shows production levels disaggregated by domestic supply (red) and production for exports (blue).*

By comparing the absolute increase in domestic sales and production of EV from 2021 to 2035 we can identify three clusters of countries (Figure 19): non-producer countries, international net buyers of EV to satisfy the domestic demand and international net producers of EV. Countries like Mexico, Brazil, Slovakia, and Canada could be greatly benefited by the increase in EV demand in other countries, as they will produce more EVs than the increase in sales in their domestic market.

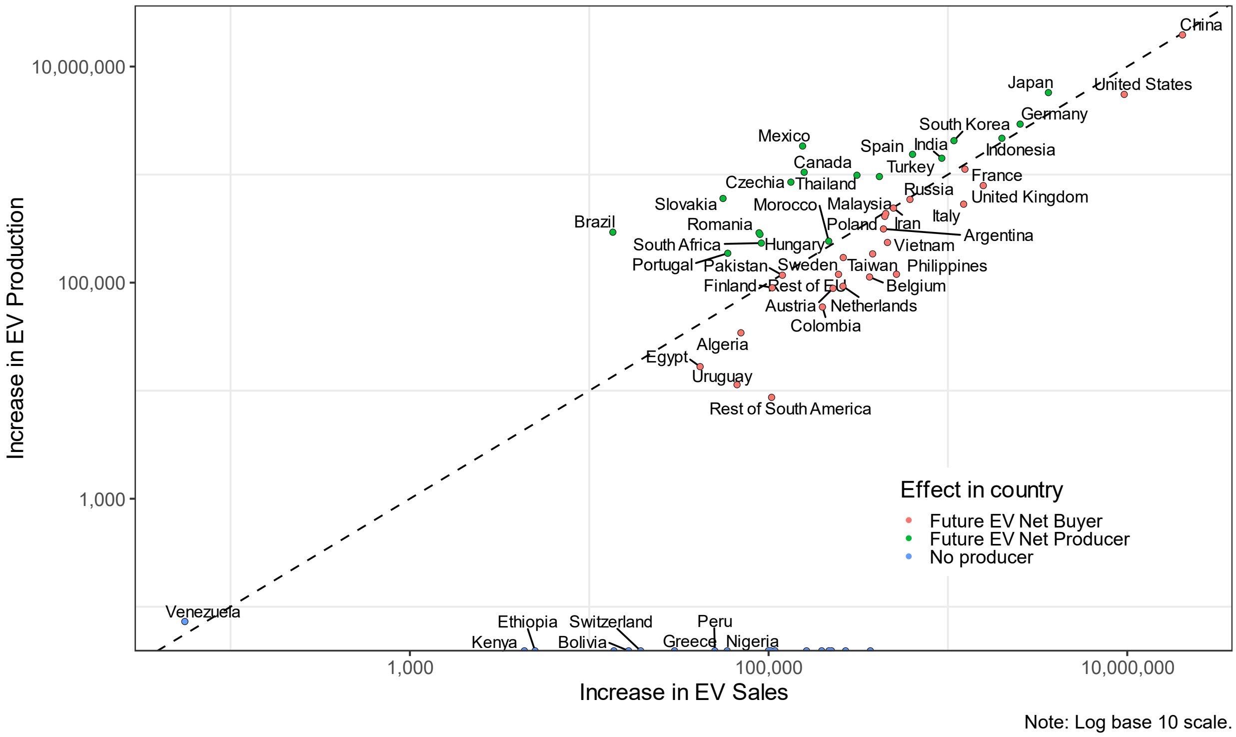

Figure 19*: Increase in EV production against increase in EV sales by 2035, using scenario 1 for production allocation (constant LDV 2019 trade ratios). Note that the scale for both axis is in log base 10. Three clusters of countries are highlighted: non-producer countries (blue), international net buyers of EV to satisfy the domestic demand (red) and international net producers of EV (green).*

Scenario 1 Results: Mexico and North America

For the North America region, we can visualize the 2035 international EV market using a Sankey diagram, observing that the biggest consumer of EVs in North America is the US, supplied mostly domestically and by Japan/Korea and Mexico. We observe that the production of Mexico and Canada are almost entirely to export to the United States. Under current LDV trade relationships, the automotive industry of Mexico depends strongly on the United States market. A similar dynamic is observed for the flow of battery capacity among countries, where the production of EVs in Mexico will mostly need to accommodate the battery requirements for the US market.

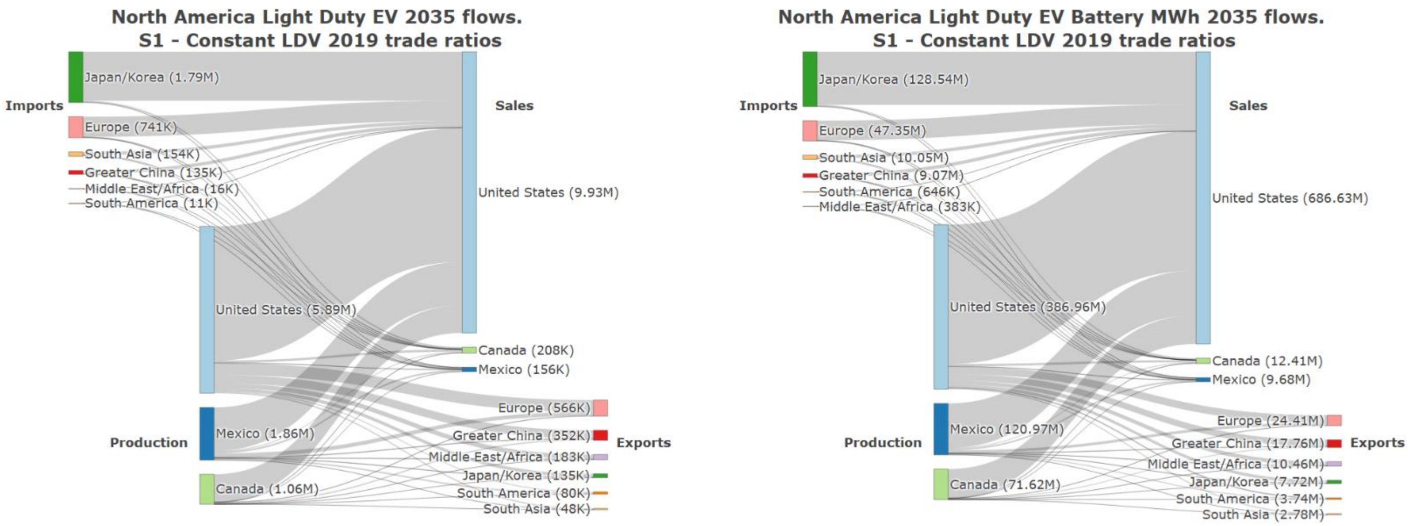

Figure 20: *2035 Light-duty EV Market for North America. Left-side shows EV vehicle production and right-side the battery requirement. Production was allocated using scenario 1 - constant LDV 2019 ratios. Left side represents the origin of the EV (production) and the right side represents the destination (domestic sales). Flows represent units of light-duty EVs (left) or MWh battery capacity (right).*

Production in all trade scenarios: Mexico

This section explores the impact of the four production scenarios on the Mexican EV production in 2035. The scenarios are: S1 (baseline scenario)- replicate the LDV trades of 2019 (the last year before COVID) with the 2035 EV trades; S2 – "Higher domestic supply" scenario, assumes an increase in the domestic supply for each country that results from policies that reduce free flows and increase protectionism; S2b – "Higher domestic supply + USMCA", the same set of assumptions as S2 but including Canada the United States, and Mexico as one region without trade barriers; and scenario S3 - "Global free trade" replicates low barriers for global flows of EVs and considers an increase in the trade flows among top 2021 EV exporting countries.

Figure 21 presents the total LDV and EV present production and forecasted production (2035) for Mexico under the 4 scenarios, presenting the detail of country of destination of the production. For EV production we observe important differences: in the higher domestic supply scenario in North America (2b) Mexico has a production of 2.2 million EVs, and in the higher domestic supply globally and global free trade scenarios (S2 and S3) the production in Mexico reduces to 1.3 and 1.4 million EVs, respectively. In all modelled scenarios the vast majority of Mexico's EV production is for the US market, showing the strong dependence of the future electric automobile Mexican industry in their neighbor country. For the projected production of LDVs, Mexico industry is more diversified, it has a higher share of production going towards domestic supply, South America, and Canada.

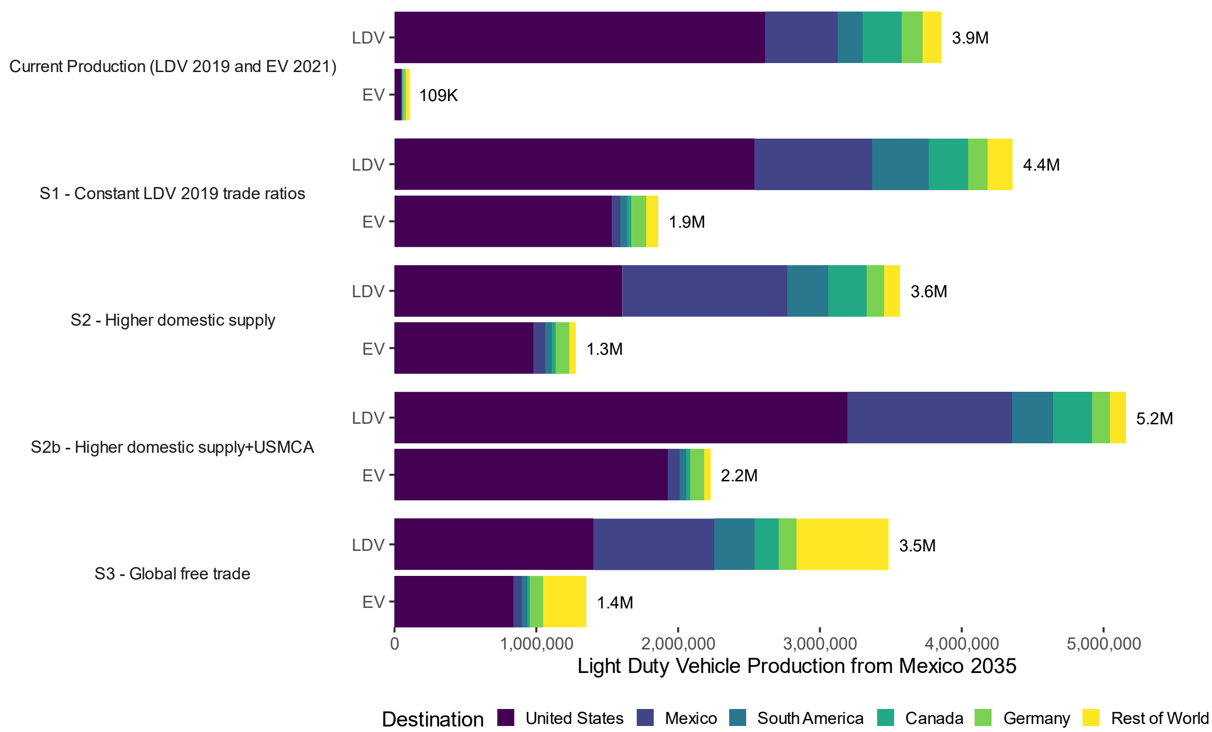

Figure 21: *Mexico's Light duty vehicle production in 2035 under all different scenarios. Only the major export partners are presented in detail. LDV: Light Duty Vehicle. EV: Light Duty Electric Vehicle.*

Figure 22 presents the battery requirements for the projected EV production of Mexico, as well as current (2021) requirement. As in every scenario the main buyer of EVs will be US, the battery capacity required will strongly depend on the market preferences of the US, which tends to favor bigger vehicles with a higher battery capacity required per vehicle.

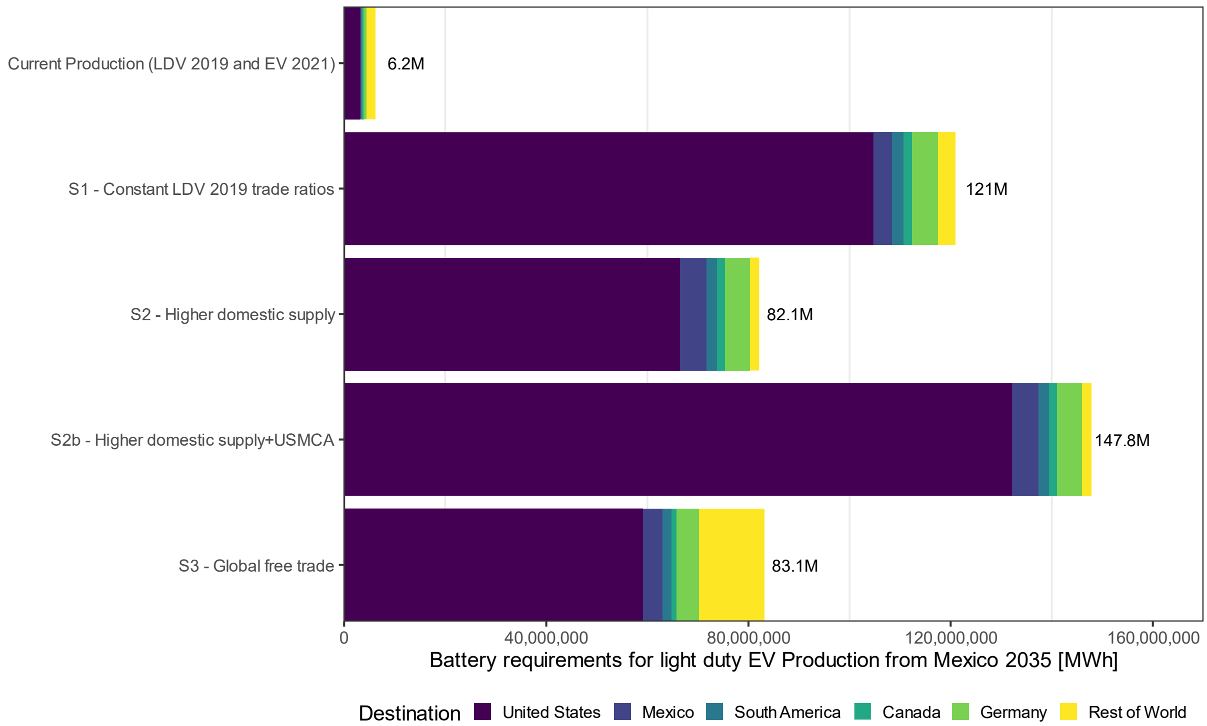

Figure 22: *Mexico's battery requirement to meet 2035 EV production under all different scenarios. Only the major export partners are presented in detail.*

Our modeling shows that, under all scenarios, with a current LDV production capacity of close to 3.5 million per year, Mexico will need to expand its capacity between 3% to 49% in order to accommodate the required production to supply its 2035 projected market demand. By then, EVs will make up between 36% to 43% of demand which OEMs in the country should be able to accommodate by strategically shifting their production lines as they expand their productive capacity. However, the difference between ICEV and EV production is the need for LiBs, a constraint that could prove critical for EV production, especially as global demand increases exponentially.

Figure 23 shows that in 2021, OEMs in Mexico installed approximately 6.2 GWh of LiBs across 109,350 EVs. All the batteries installed were imported, as Mexico does not currently have any battery production capacity. Although CATL, BMW, and Cenntro Automotive Mexico have announced plans to launch battery production in the country, only CATL has provided a clear estimate of its intended production of 80 GWh, while BMW and Cenntro Automotive Mexico have so far only disclosed their committed investment numbers, with $500 million and $200 million respectively. Based on CATL's cost per GWh, we have estimated their combined production at 12 GWh.

Our estimations suggest that, considering the current battery import levels and projected domestic production, battery availability in Mexico will not be a constraint for EV production under scenarios 2 and 3. However, there would be a significant gap under scenarios 1 and 2b that would need to be addressed by either increasing production or securing foreign battery supply to ensure streamlined EV production and avoid losing market share.

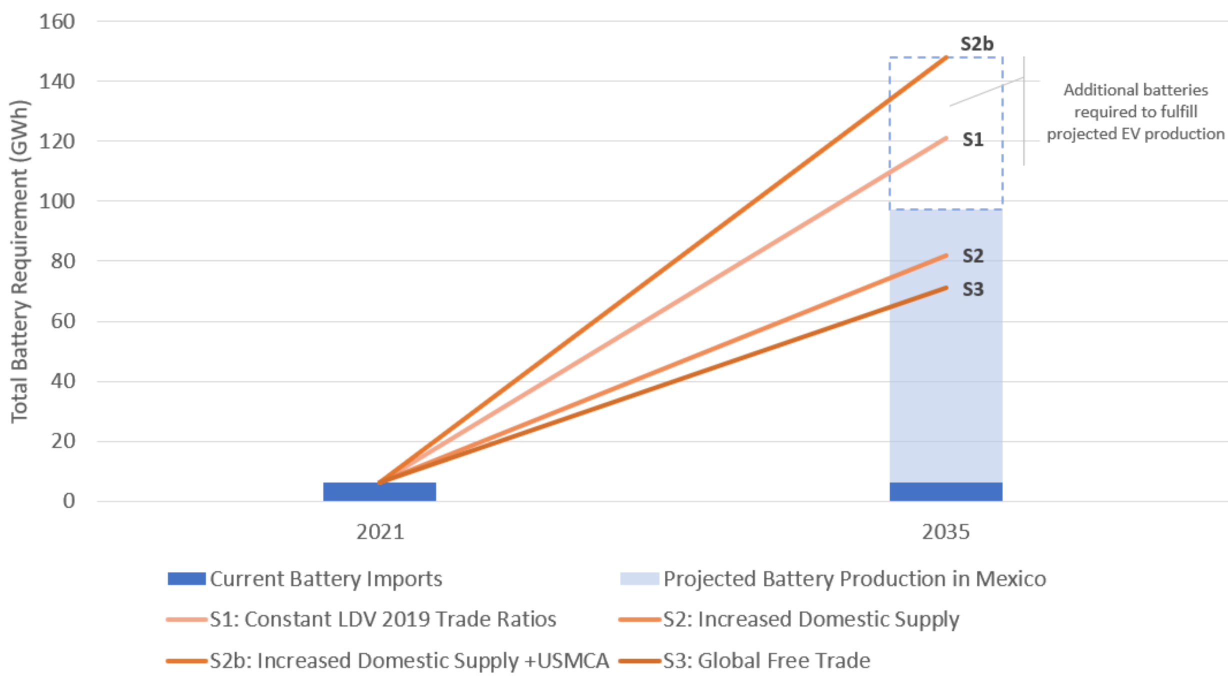

Figure 23: *Current EV battery supply for production in Mexico and the requirement in 2035 under the four production scenarios. Battery production in Mexico by 2035 is estimated from current production announcements by CATL, BMW, and Cenntro Automotive Mexico.*

North America EV production under different scenarios

Error! Reference source not found. presents the EV market under scenario 2b (higher domestic s upply + UMSCA) and scenario 3 (global free trade). We can observe that Mexico production increases in a higher domestic supply scenario under the United States-Mexico-Canada Agreement (UMSCA) partnership, as a bigger share of the United States market is supplied by Mexico and Canada. Under the global free trade scenario, other countries with more mature EV production, such as Japan and European countries, capture a bigger share of United States demand, reducing the share for Mexico and Canada.

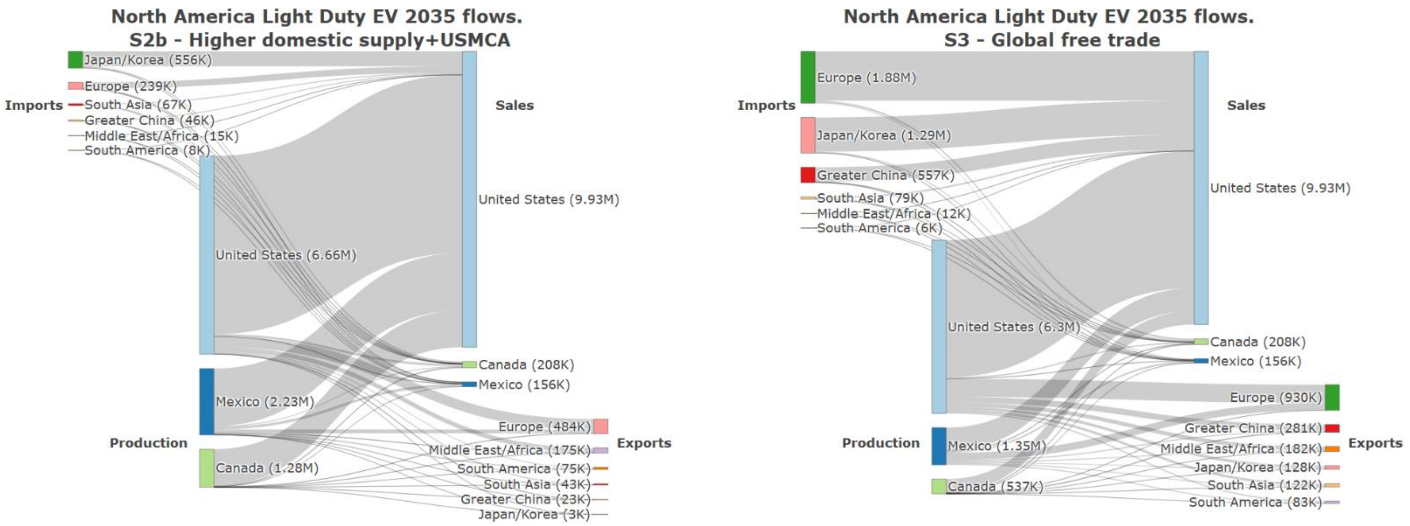

Figure 24: *North America Light Duty EV Market under scenario 2b (higher domestic supply + UMSCA) and scenario 3 (global free trade).*

Potential expansion to other markets

Next we observe potential markets for EV expansion, that will be supplied by other regions of the world (Figure 25). The three biggest consumers of EVC in South America will be Argentina, Chile and Colombia, with a combined demand of 1.1 M EVs in 2035. The supply will mostly come from internal production for Argentina, Japan and China for Chile and Brazil for Colombia. South Asia presents a bigger demand of around 4.6 million EVs in 2035. In the baseline scenario their supply will be met mostly by internal production, with a small share produced by China, Japan, and Korea.

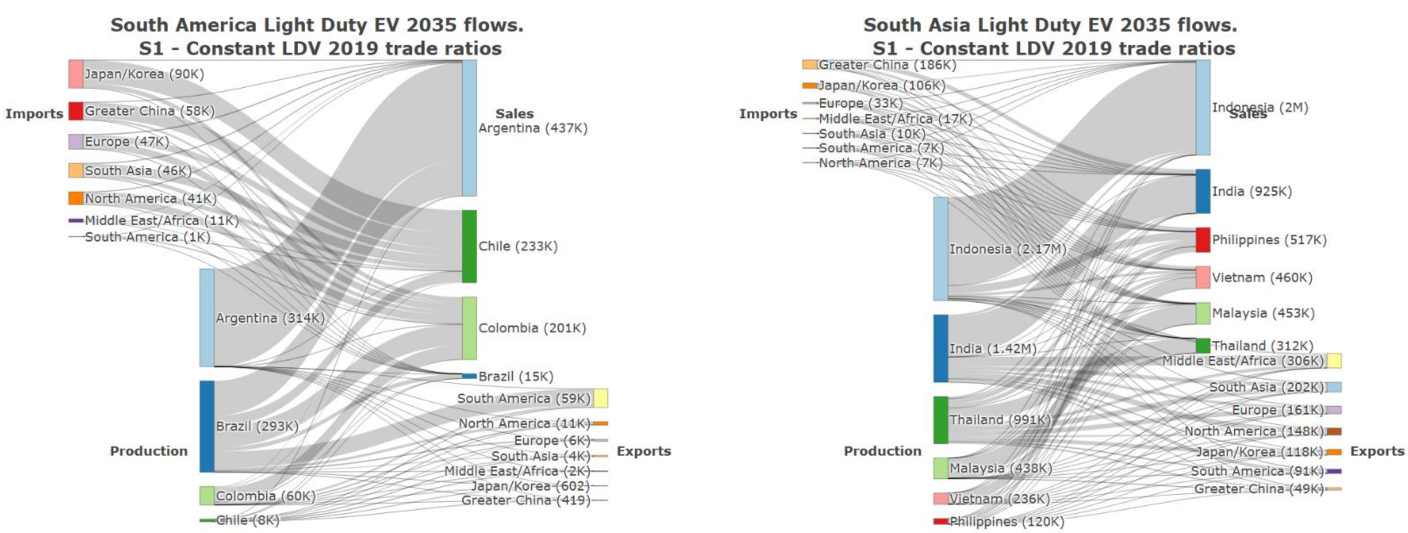

Figure 25: *South America (left) and South Asia (right) light duty EV Market flows for 2035.*

All Trade Scenario Results: Production Main Regions

Figure **26 26**26 presents the EV production for each country under the 4 different production scenarios considered. We observe that China always produces around 20 million units, due to the modeling assumption that the high share of domestic supply in LDV 2019 will be similar for EVs. For Mexico, we observe a production of 1.9 million units in the baseline scenario (S1), and a decrease in production in both the higher domestic supply and global free trade scenarios. The decrease in production in S3 is due to the decrease of exports to the United States, and in the global free trade scenario (S4) Mexico does not get a big share of exports to other countries due to their current low participation in the 2021 EV global market. The scenario with higher domestic supply but with the inclusion of the USMCA partnerships shows the biggest production for Mexico, due to an increase in exports to their main commercial partner: United States.

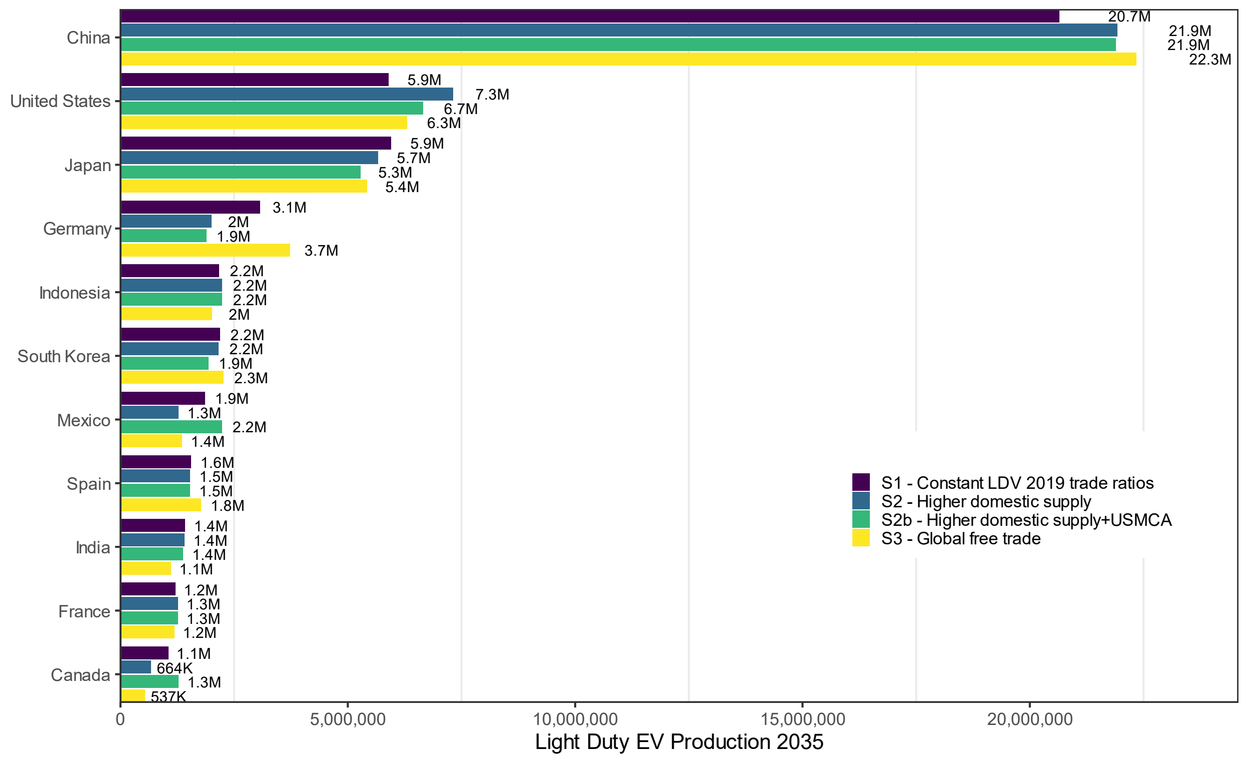

***Figure 26 26**: Light duty EV production in 2035 under different scenarios. Only the top twelve producing countries are presented.*

Policy Discussion

The current domestic market for light-duty vehicles in Mexico is about 1.32 million vehicles per year, while production is about 3.86 million vehicles per year, most of which is exported to the US. The US light-duty vehicle market is saturated, with vehicle ownership at approximately 80%, and sales have remained relatively stable, with annual unit sales oscillating between 15-17 million. In contrast, modeling shows that Mexico is expected to witness a 62% growth in its light-duty vehicle market by 2035, driven by its higher population growth rate and low vehicle ownership.

Other lower- and middle-income countries and regions are also poised to experience significant expansions in their light-duty vehicle markets, including Africa and the Middle East, South America, Indonesia, and the rest of South Asia. The expected growth in local demand together with the growth in other developing markets will help the Mexican industry grow the total LDv production in most scenario other than the free trade where the local market will be shared with higher level of imports (figure 21).

Historically highly motorized countries will experience a large uptake of electric vehicles (EVs) by 2035, taking up a considerable proportion of their total light-duty vehicle sales. For Mexico's export-oriented automakers, this shift presents a unique opportunity and risk with the need to secure a competitive advantage by capitalizing on the rising EV market. All four scenarios in our model suggest that in order to keep the light-duty vehicle market share, one third to 45% of the production in 2035 will have to be of EVs. Thus, when planning for the EV transition, it's essential to add capacity rather than only replacing it, by investing in new production facilities and equipment.

The most significant advantage that the Mexican automotive industry could have in the global shift to EVs under current policies is by incentivizing North American-made parts, combined with provisions established by the Biden administration in the 2022 Inflation Reduction Act (IRA) that expand tax credits to purchase EVs assembled in the region. This cements Mexico as the most strategic investment location for foreign automakers to access the massive North American Market. Scenario 2, reflecting higher domestic supply for the US, Canada, and Mexico, and scenario 3, reflecting global free trade, yield similar low EV production for Mexico of 1.3-1.4 million a year. While scenario 2B, reflecting higher domestic supply under the USMCA region, yields the highest EV supply of 2.2 million a year out of 5.2 million light-duty vehicles.

Mexico's heavy dependence on the US market could hinder its ability to compete globally in an open market scenario, as indicated in scenario S3. Therefore, Mexico must maintain a strong relationship with the US market while exploring opportunities to expand its market reach. Mexico could leverage its position by being a pioneer in supplying EVs not only for North America but also for Central and South America, offering a diverse range of EVs from large and expensive ones to more affordable options with smaller batteries. In doing so, Mexico could position itself as a leading supplier to the rapidly expanding markets of the lower- and middle-income countries.

The Mexican auto industry's reliance on the US market is a significant factor affecting its transition to electric vehicles, as the US market demands larger battery sizes per vehicle than the global average. Current investment does not cover the new demand thus, the Mexican auto industry will have to work to secure a proportionally high battery supply to meet this demand, most likely through imports.

Our analysis suggests that the Mexican EV industry is heavily dependent on regional trades agreements and the decision of large international OEMs that can shift production within North America and globally. Diversifying the OEM's represented in Mexico and especially promoting new EV only OEMs may help reduce the dependency and create a more stable industry. furthermore, developing new markets for LDV's in general and EV's specifically in markets that are expected to grow in the middle and long range such as Latin America may also help diversifying the demand, reduce the battery capacity per vehicle demand and create a long-term change.

Conclusions and Limitations

This report presents an analysis of current production and sales trends and provides scenarios for international trade. To gain a better understanding of the barriers and opportunities in the transition to the electric vehicle industry, further modeling of the demand for batteries and minerals is critical. We aim to develop our modeling tool to include additional vehicle categories and technologies that better reflect the global market and current and future supply. In future work, we plan to refine these scenarios by interviewing industry experts to explore changes in production and the decision-making processes of international OEMs. We also would like to add additional considerations such as labor, transportation, and others into the tool decision process.

Furthermore, we recognize the importance of considering the entire supply chain, including tier 1-3 suppliers, and suggest a focus on the labor implications of the industry change. While the current analysis focuses only on light duty vehicles and ends in 2035, we acknowledge the need to expand our analysis to include the demand from medium and heavy-duty vehicles, as well as electric transit, to fully understand the demand for batteries and the industry transition.

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Appendix

Production details by Scenario

Scenario 1 - Constant LDV 2019 trade ratios

Shown in detail in Results section.

Scenario 2 – Higher domestic supply

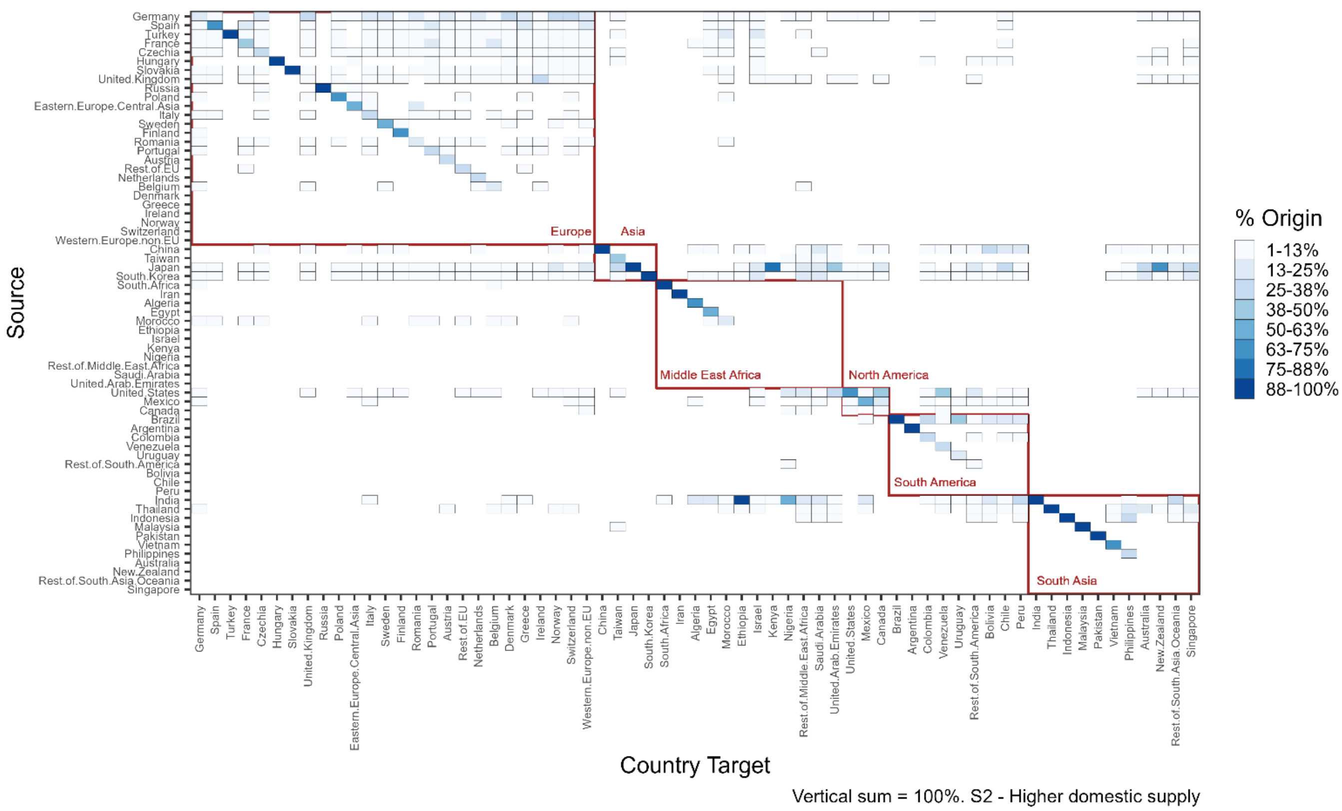

Figure 27: *Trade ratios assumed for Scenario 2 – Higher Domestic Supply. Countries are sorted by region and production levels. The vertical sum for each country will equal 100%, which corresponds to the total supply for the domestic demand. Blank cells indicate no trade relation.*

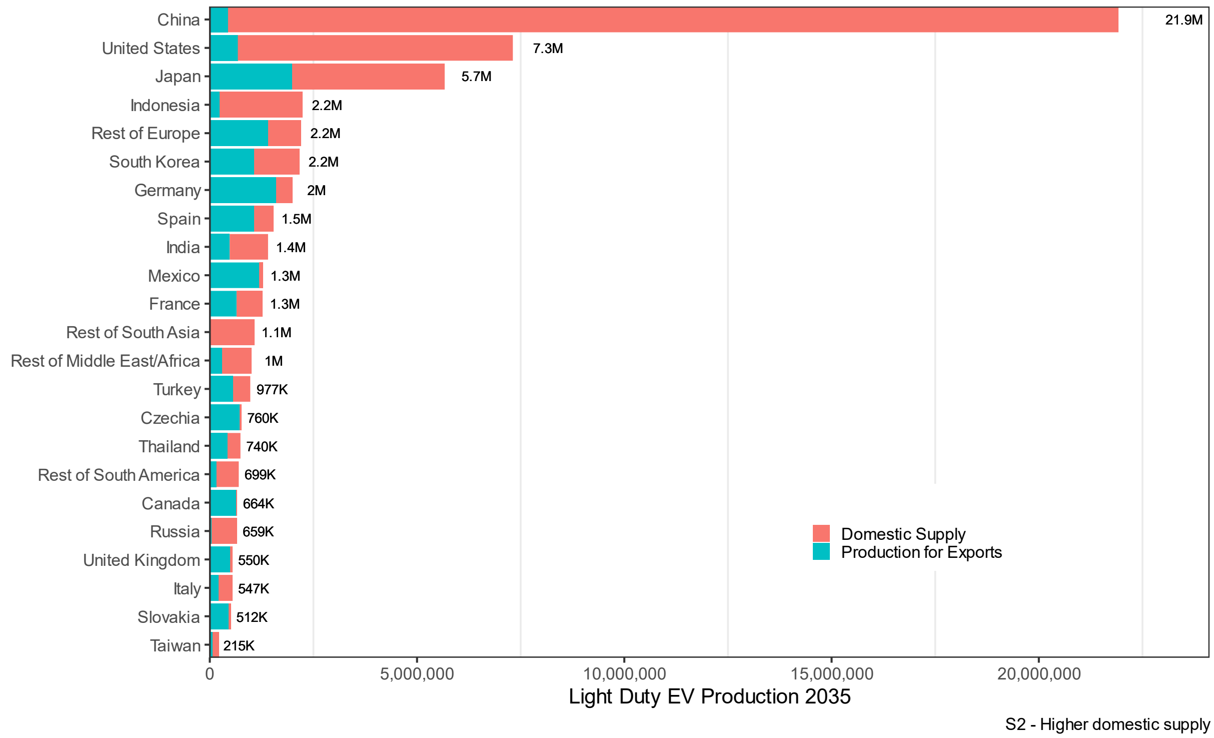

Figure 28*: Projected light duty EV production for 2035 - Scenario 2. Production levels are shown disaggregated by domestic supply (red) and production for exports (blue).*

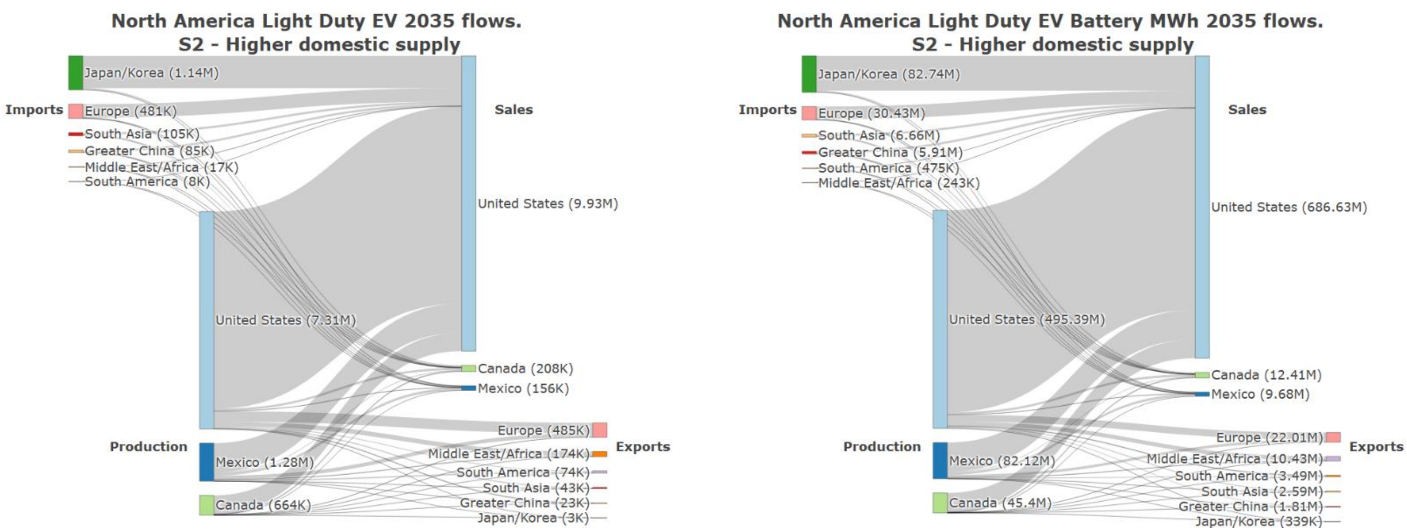

Figure 29*: 2035 Light-duty EV Market for North America. Left-side shows EV vehicle production and right-side the battery requirement. Production was allocated using scenario 2 - Higher domestic supply. Left side represents the origin of the EV (production) and the right side represents the destination (domestic sales). Flows represent units of light-duty EVs.*

Scenario 2b – Higher domestic supply + USMCA

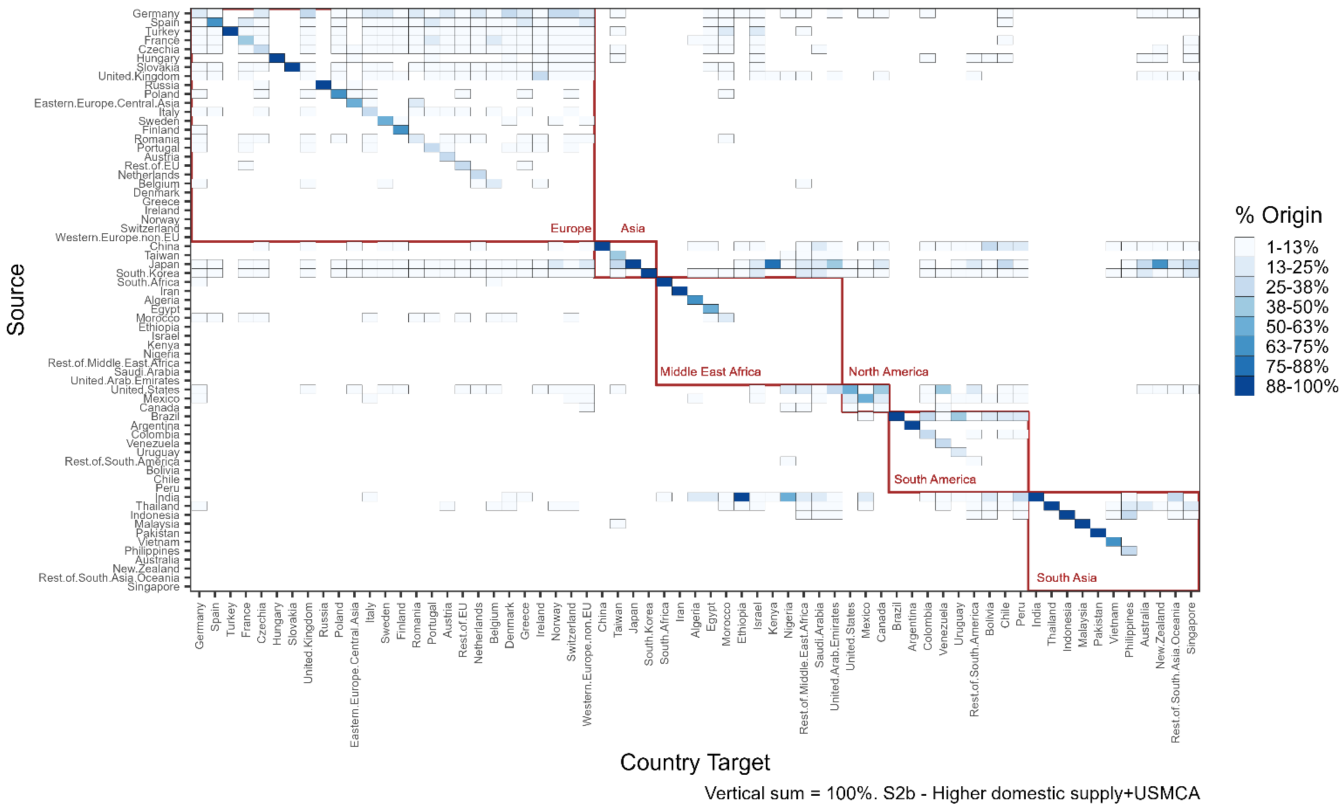

***Figure 30**: Trade ratios assumed for Scenario 2b – Higher Domestic Supply + USMCA. Countries are sorted by region and production levels. The vertical sum for each country will equal 100%, which corresponds to the total supply for the domestic demand. Blank cells indicate no trade relation.*

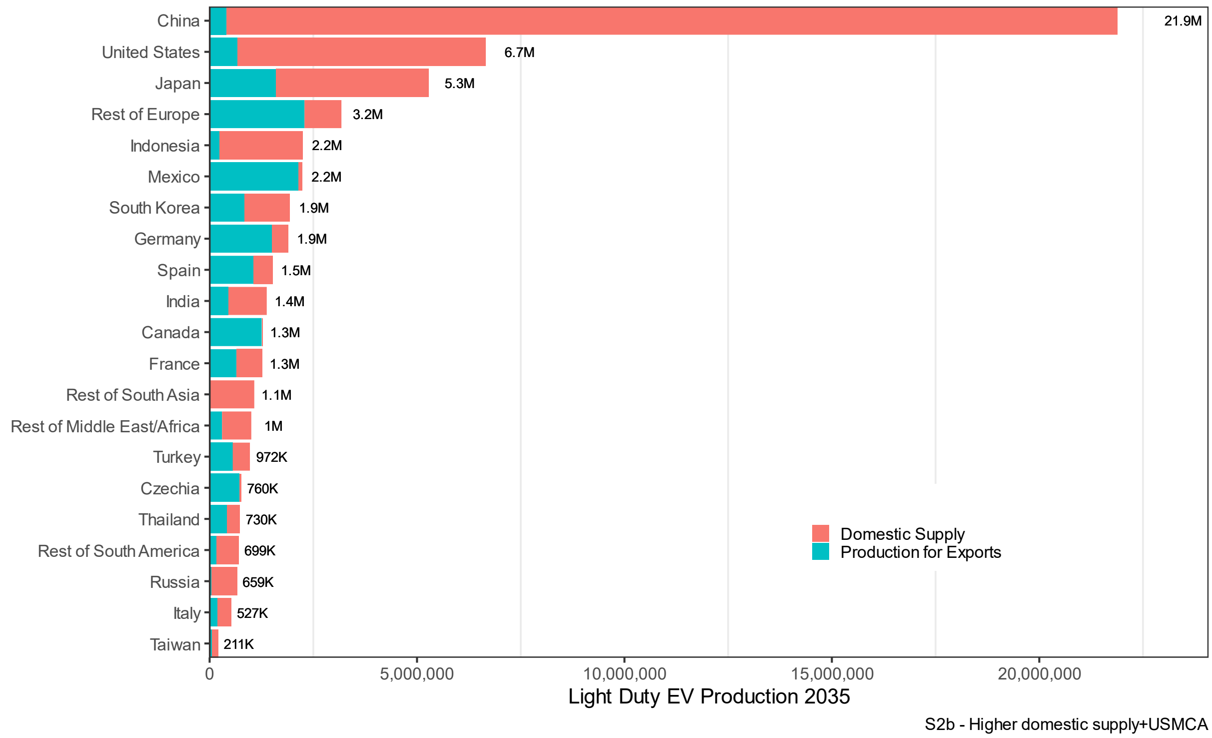

***Figure 31**: Projected light duty EV production for 2035 - Scenario 2b. Production levels are shown disaggregated by domestic supply (red) and production for exports (blue).*

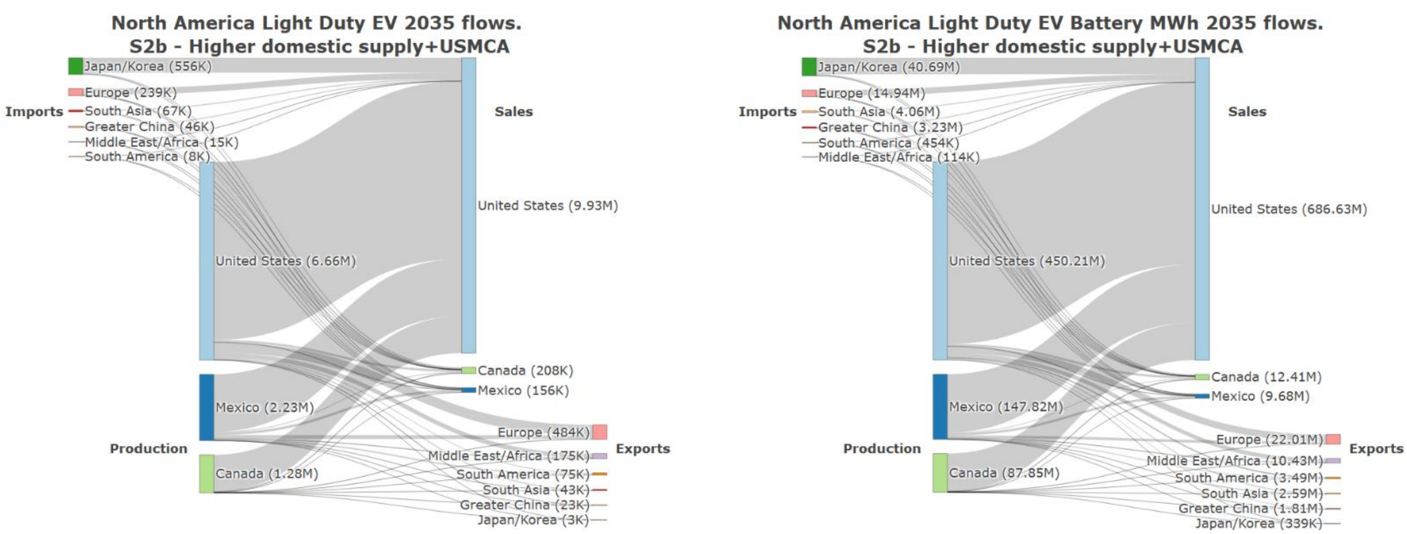

***Figure 32**: 2035 Light-duty EV Market for North America. Left-side shows EV vehicle production and right-side the battery requirement. Production was allocated using scenario 2b - Higher domestic supply + UMSCA. Left side represents the origin of the EV (production) and the right side represents the destination (domestic sales). Flows represent units of light-duty EVs.*

Scenario 3 - Global free trade

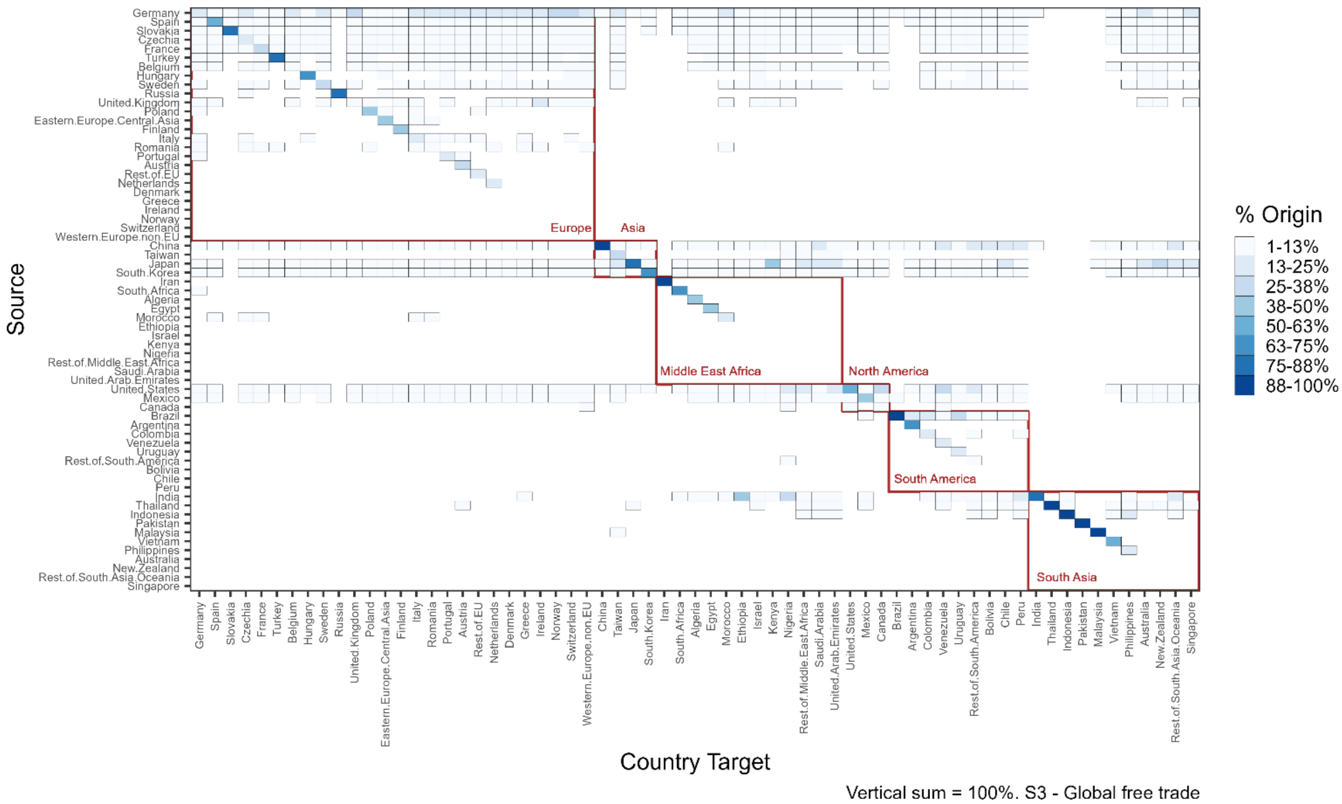

***Figure 33**: Trade ratios assumed for Scenario 3 – Global free trade. Countries are sorted by region and production levels. The vertical sum for each country will equal 100%, which corresponds to the total supply for the domestic demand. Blank cells indicate no trade relation.*

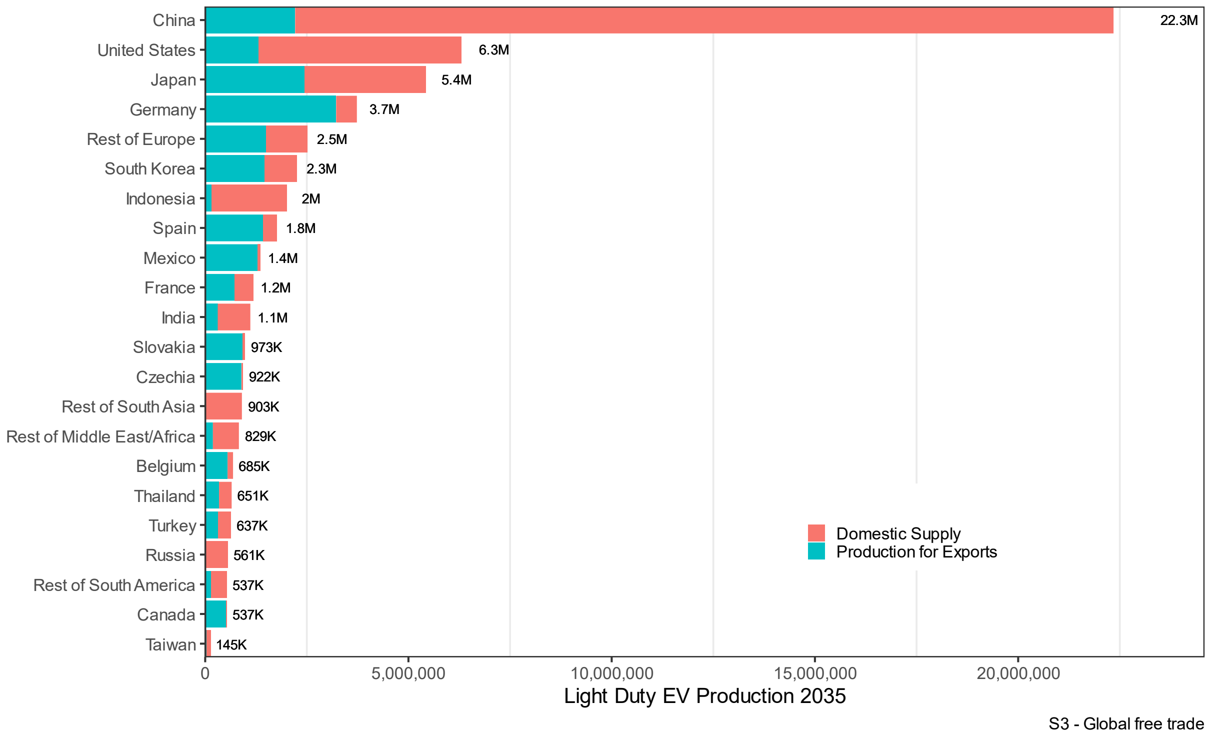

***Figure 34**: Projected light duty EV production for 2035 - Scenario 3. Production levels are shown disaggregated by domestic supply (red) and production for exports (blue).*

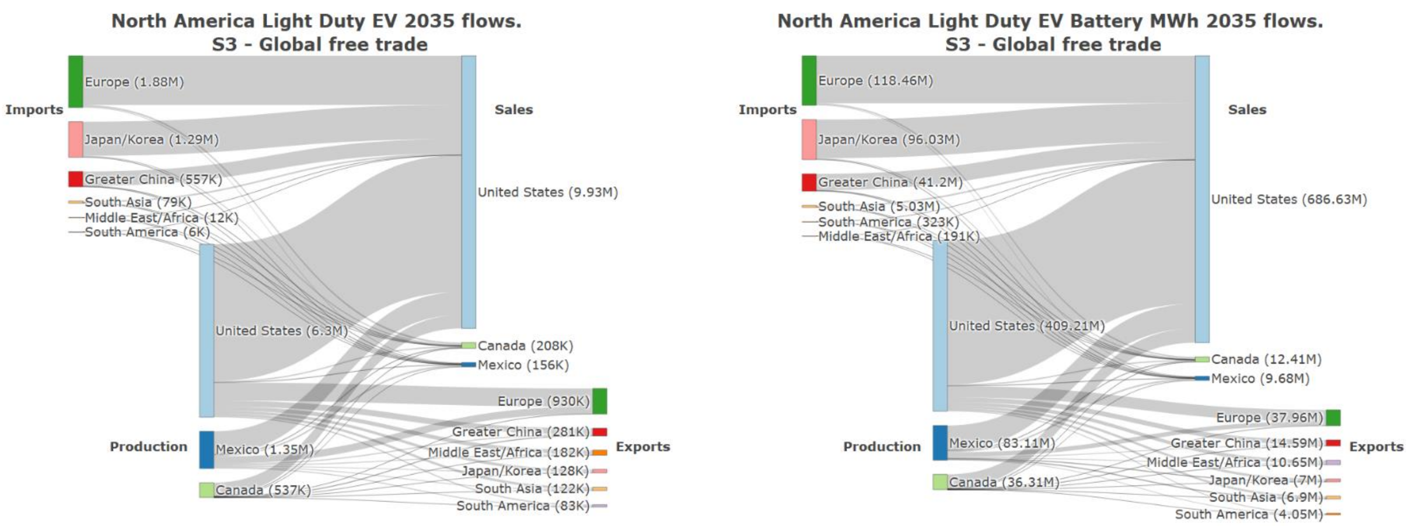

***Figure 35**: 2035 Light-duty EV Market for North America. Left side shows EV vehicle production and right-side the battery requirement. Production was allocated using scenario 3 - Global free trade. Left side represents the origin of the EV (production) and the right side represents the destination (domestic sales). Flows represent units of light-duty EVs.*