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THE GLOBAL AUTOMAKER RATING 2022

Who is leading the transition to electric vehicles?

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While the ICCT typically supports government policymakers and regulators as they develop policies to reduce transportation emissions, this report is for a wider audience. We believe the same approach we use to support government regulations—that is, providing timely, high-quality data and analysis to decision-makers—can help inform investors, the broader financial sector, consumers, and auto companies at this critical time in the industry.

This report offers an expert, in-depth analysis and compares global automakers in the transition to zero-emission vehicles. Our assessment might be of value to investors and rating companies. Consumers might also be interested in knowing how much effort each automaker is making to transition to a fully decarbonized vehicle market and supply chains. And auto companies themselves, all of which have pledged to achieve carbon neutrality, might find a data-driven, transparent assessment of their actions and plans a valuable yardstick as they work to find opportunities to improve.

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EXECUTIVE SUMMARY

This report rates how the world's largest auto manufacturers stack up in the transition to electric vehicles (EVs). Major manufacturers are striving for fleets with zero tailpipe emissions; success in that is necessary for the world to mitigate the worst effects of climate change. To evaluate the work of manufacturers toward that goal, we rate them on 10 custom-built metrics that reflect both what they are doing now and what they say they will do in the near future. We evaluate their current fleets and production processes and assess their stated future plans, policies, and priorities. Our approach is a meaningful and comprehensive way to distinguish forward-looking automakers from their less-progressive counterparts.

Focused on the top 20 light-duty vehicle manufacturers in the world by sales in 2022, this report adds an important missing piece to global research and analysis regarding how today's major automakers are transitioning to zero-emission vehicles (ZEVs). Our rating is quantitative and transparent; we present full details of our chosen methodology and data sources. Additionally, the ICCT contacted all the automakers assessed in this report to seek to verify the data we collected.

Many ratings reports are vague in emphasis and often cover thousands of companies with a broad environmental, social, and governance (ESG) lens. This report is different. We use our deep expertise in the field to present a focused, incisive rating that compares automakers in this time of unprecedented transformation in the industry. For example, this analysis is built on a comprehensive database that includes both sales and key specifications of EVs in six major vehicle markets. This report also considers the real-world electric drive share of plug-in hybrid electric vehicles (PHEVs).

Because our rating includes both present and future performance indicators, we group our 10 metrics by three pillars: market dominance, technology performance, and strategic vision. These serve as the basis for our overall rating results. Table ES1 presents the three pillar scores; the overall 2022 ratings are in the rightmost column. This final score reflects each company's comparative position in the ZEV transition. The automakers are listed in order from highest to lowest scoring. "Leaders," shown in green, scored in the top third of the rating (66.7–100). "Transitioners," in yellow, scored in the middle third (33.4–66.6). "Laggards," in red, scored in the bottom third (0–33.3).

Table ES1. Overall scores, The Global Automaker Rating 2022

	MARKET DOMINANCE	TECHNOLOGY PERFORMANCE	STRATEGIC VISION	2022 rating	
Tesla	69	80	100	83	LEADERS
BYD	78	57	83	73	
BMW	31	78	57	56	TRANSITIONERS
VW	49	63	47	53	
Stellantis	48	38	63	50	
Geely	55	51	39	48	
Renault	43	37	61	47	
Mercedes-Benz	36	53	47	45	
GM	20	52	63	45	
SAIC	65	28	39	44	
Great Wall	43	40	32	38	
Ford	14	55	44	38	
Hyundai-Kia	35	58	20	38	
Chang'an	52	13	41	36	
Toyota	32	43	15	30	LAGGARDS
Honda	19	32	32	28	
Nissan	33	18	31	27	
Tata	15	41	23	27	
Mazda	7	4	18	10	
Suzuki	0	0	0	0	

The **market dominance pillar** reflects the progress automakers have made in the transition to ZEVs in their own fleets (see Table ES2). We analyze each automaker's ZEV-equivalent sales shares, which is the EV share of total light-duty vehicle sales, including battery-electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and PHEVs. For PHEVs, we assess only the share of driving that is on electricity by considering real-world driving behavior. We also assess the share of eight light-duty vehicle classes, ranging from mini/subcompact car to pick-up truck, that are covered by available ZEV models from each automaker.

The leaders in the market dominance pillar, Tesla and BYD, already produce only EVs. Tesla only produces BEVs, and in March 2022, BYD shifted to only manufacture EVs (i.e., both BEVs and PHEVs). All other automakers lag significantly in ZEV sales shares, although some succeed in offering coverage across all eight light-duty vehicle classes.

Table ES2. Ratings on market dominance

	MARKET DOMINANCE			
	ZEV-equivalent sales share (0-100)	Class coverage (0-100)	Pillar score (0-100)	
BYD	69	88	78	LEADERS
Tesla	100	38	69	LEADERS
SAIC	31	100	65	TRANSITIONERS
Geely	23	88	55	TRANSITIONERS
Chang'an	16	88	52	TRANSITIONERS
VW	10	88	49	TRANSITIONERS
Stellantis	8	88	48	TRANSITIONERS
Renault	11	75	43	TRANSITIONERS
Great Wall	10	75	43	TRANSITIONERS
Mercedes-Benz	10	63	36	TRANSITIONERS
Hyundai-Kia	8	63	35	TRANSITIONERS
Nissan	4	63	33	LAGGARDS
Toyota	1	63	32	LAGGARDS
BMW	12	50	31	LAGGARDS
GM	2	38	20	LAGGARDS
Honda	0	38	19	LAGGARDS
Tata	6	25	15	LAGGARDS
Ford	4	25	14	LAGGARDS
Mazda	1	13	7	LAGGARDS
Suzuki	0	0	0	LAGGARDS

The **technology performance pillar** rates the automakers' levels of technological advancement in meeting consumer needs and reducing upstream emissions. In this pillar, we rate five metrics. On vehicle performance, the energy consumption metric analyzes the potential for BEVs to lower electricity costs for consumers and reduce the cost and environmental impacts of making batteries; charging speed assesses how quickly a BEV can recharge its battery; and driving range reflects how far a ZEV can travel before recharging or refueling as an important element of convenience for consumers. On the upstream emissions, the renewable energy metric analyzes how much progress an automaker has made in switching to 100% renewable electricity in vehicle production and assembly and battery manufacturing. The battery recycling and repurposing metric assesses how much progress an automaker has made in starting to recycle and reuse batteries from its EVs (see Table ES3).

Most automakers are making progress in vehicle technology and score highly in at least one of the technological attributes that will lead to greater consumer satisfaction with

and acceptance of ZEVs. This is clearly a priority for automakers. However, there is a long way to go in sustainable vehicle manufacturing. Only BMW, VW, and Mercedes-Benz have made strong progress in using 100% renewable electricity. Although some automakers show stronger progress on battery recycling and repurposing than others, all need to expand in this area for their future supply chains to be sustainable. To thrive in a zero-carbon future, most automakers will need to surpass the current best performer in the market.

Table ES3. Ratings on technology performance

	TECHNOLOGY PERFORMANCE						
	Energy consumption (0-100)	Charging speed (0-100)	Driving range (0-100)	Renewable energy (0-100)	Battery recycle/ repurpose (0-100)	Pillar score (0-100)	
Tesla	100	100	100	0	100	**80**	**LEADERS**
BMW	72	52	76	100	92	**78**	
VW	60	51	82	75	49	**63**	**TRANSITIONERS**
Hyundai-Kia	32	75	73	11	100	**58**	
BYD	74	38	73	0	100	**57**	
Ford	26	49	95	14	91	**55**	
Mercedes-Benz	55	41	73	50	43	**53**	
GM	53	31	78	0	99	**52**	
Geely	45	32	68	9	100	**51**	
Toyota	43	35	70	6	59	**43**	
Tata	87	3	21	6	87	**41**	
Great Wall	55	15	30	0	100	**40**	
Stellantis	28	36	28	0	98	**38**	
Renault	49	13	32	0	90	**37**	
Honda	51	26	52	0	32	**32**	**LAGGARDS**
SAIC	49	0	0	0	90	**28**	
Nissan	19	12	29	0	31	**18**	
Chang'an	45	4	19	0	0	**13**	
Mazda	0	19	3	0	0	**4**	
Suzuki	N/A	N/A	N/A	0	0	**0**	

The **strategic vision pillar** rates how focused automakers are on ZEVs in their longer-term planning by three metrics (see Table ES4). The ZEV target metric analyzes the extent to which automakers have set long-term targets for ZEV sales share consistent with what is needed to keep global warming below 2 °C. The ZEV investment metric assesses the total announced investment in ZEV research and development (R&D),

ZEV and battery manufacturing sites, and infrastructure, relative to the size of an automaker. And finally, the executive compensation metric examines the degree to which each automaker's top executive's pay is tied to progress in EV development.

Many automakers are committed to ZEVs. Indeed, nine have committed to a full transition to ZEVs in the leading vehicle markets by 2035 for at least one brand; nearly all have announced major investments in ZEV development.

However, few automakers leverage executive pay. Some link executive compensation broadly to ESG performance. Only five (Stellantis, BMW, GM, Renault, and Nissan) tie the pay of their top executive directly to progress in EV development for even a fraction of the compensation package. Companies striving to catch up in the transition to ZEVs should consider using this potentially powerful tool.

Table ES4. Ratings on strategic vision

	STRATEGIC VISION				
	ZEV target (0-100)	ZEV investment (0-100)	Executive compensation (0-100)	Pillar score (0-100)	
Tesla	100	100	100	**100**	**LEADERS**
BYD	70	79	100	**83**	
GM	96	36	57	**63**	**TRANSITIONERS**
Stellantis	81	9	100	**63**	
Renault	100	45	37	**61**	
BMW	72	20	80	**57**	
Mercedes-Benz	96	34	12	**47**	
VW	92	23	26	**47**	
Ford	96	36	0	**44**	
Chang'an	68	56	0	**41**	
SAIC	37	81	0	**39**	
Geely	71	46	0	**39**	
Great Wall	92	5	0	**32**	**LAGGARDS**
Honda	73	24	0	**32**	
Nissan	60	24	7	**31**	
Tata	52	18	0	**23**	
Hyundai-Kia	39	20	0	**20**	
Mazda	30	25	0	**18**	
Toyota	39	7	0	**15**	
Suzuki	0	0	0	**0**	

From our overall rating for 2022, we draw three broad conclusions:

Most automakers score well on at least one metric. This reflects the complexity and breadth of the ZEV transition, as well as differing approaches from automakers. Of the automakers that lead the 2022 rating, Tesla is making 100% ZEVs and BYD's market share for ZEVs and PHEVs has reached 99%. Some automakers, including Chang'an, Geely, SAIC, Stellantis, and VW, are developing a wider spectrum of light-duty ZEV models from small cars to small trucks. Some, including BMW, Ford, GM, Hyundai-Kia, Mercedes-Benz, and VW, have focused on improving some of the technological attributes important to consumers. BMW, VW, and Mercedes-Benz are also working to reduce their upstream manufacturing emissions. Many automakers have established ZEV targets and are investing to meet those targets. By rating manufacturers on a broad set of metrics, our analysis offers a sharp, balanced view of their strengths and weaknesses.

Every automaker has work to do. Even Tesla's and BYD's ratings were weak on some metrics. For example, our rating shows that Tesla needs to offer more models across the size spectrum. In 2022, Tesla offered models in only three out of eight vehicle classes we identified. Similarly, BYD has work to do to improve the technological attributes important to consumers. As the transition accelerates, all companies must evolve and grow to keep pace with the changing market.

Manufacturers headquartered in Japan and India must work to catch up to competitors in the transition. All five manufacturers headquartered in Japan and Tata, headquartered in India, are at the bottom of our rating. To improve, they need to increase their EV sales, set public ZEV targets, and invest in ZEVs. It is the case, though, that in the absence of effective government policies, the domestic markets for EVs in Japan and India are anemic at present. However, these companies would have rated higher if they had announced stronger targets and investment plans for the ZEV transition.

We will update this rating report annually. It will undoubtedly evolve each year as the landscape evolves and as automakers make progress. Our review will remain data-driven and will incorporate new real-world data on ZEVs as it becomes available. We will continually update our metrics as new practices emerge and existing practices mature, for example by incorporating additional elements of supply chain decarbonization. In our subsequent reports, we will continue to track automakers' progress in the complex, multi-faceted ZEV transition.

In the meantime, this report offers the definitive look at how global automakers rate in the transition to ZEVs.

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1 INTRODUCTION

Meeting the goals set in the Paris Climate Agreement will require an unprecedented transition in the auto industry away from internal combustion engine vehicles (ICEVs) to zero-emission vehicles (ZEVs). Automakers around the world will need to transition in the next decade to keep up as government policies align with climate goals and as market forces and consumer preferences push in this direction. This changing reality is already reflected in new vehicle sales. The share of electric vehicles (EVs)—this term covers battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs)—has been growing rapidly in leading markets. In 2022, China, Europe, and the United States reached 24%, 21%, and 7% EV share of new sales, respectively, for light-duty vehicles (LDVs), which include cars, vans, and light commercial vehicles such as pick-up trucks. These markets comprised around 60% of global LDV sales last year and are the leaders in vehicle policy.

Automakers that have already set targets to phase out the production of ICEVs accounted for 40% of LDV sales in 2022. It now seems that, within the foreseeable future, most new car, van, and pick-up truck sales will be EVs. For automakers accelerating efforts to transition, this is a big opportunity. At the same time, those unable to keep pace in the industry's transformation face a big risk.

This report focuses primarily on ZEVs, which are defined as BEVs and FCEVs, and we include elements that reflect the importance of moving toward zero-carbon manufacturing supply chains. PHEVs incorporate electric drivetrain technology, but real-world data shows they operate mostly on gasoline; because they generate tailpipe emissions from combusting fossil fuels, we discount PHEVs in our analysis. Additionally, we exclude vehicles that run on biofuels and e-fuels from our analysis, because previous ICCT research demonstrated that there is no realistic pathway for using alternative fuels to decarbonize ICEVs. Most conventional biofuels used today do not clearly reduce greenhouse gas (GHG) emissions compared to diesel and gasoline. While advanced biofuels made from wastes are more sustainable, they are expensive to produce and the necessary feedstocks are limited. Using e-fuels in internal combustion engines is an extraordinarily inefficient and expensive way to use renewable electricity. Only BEVs and FCEVs using 100% renewable energy are realistic ZEV pathways, as discussed in Searle et al. (2021). By our estimate, ZEV sales will need to reach almost 100% for LDVs in the major markets by 2035—and meet an interim target of 77% in 2030—to align with a 2 °C climate trajectory; additional measures will be needed to align with a 1.5 °C pathway (Sen & Miller, 2022).

While there are many published assessments of auto companies, this rating is unique among publicly available reports in its global scope and focus on a transition to a zero-emission future for the industry, rather than on broad environmental, social, and governance (ESG) criteria. Additionally, this rating is based primarily on our own collected data and analysis, rather than on corporate surveys and other self-reported information. We draw on ICCT's in-depth knowledge of the industry, major markets, and what is required to align with the Paris Agreement. Our approach is bolstered with supplemental input and insights from other experts in a handful of key areas.

We use 10 custom-built metrics to identify and evaluate efforts by the world's 20 largest LDV manufacturers by sales to decarbonize their vehicle fleets and manufacturing operations consistent with limiting global warming to below 2 °C. We examine each manufacturer's latest ZEV sales, actions to reduce manufacturing emissions, and overall strategies as key indicators of their commitment. The final rating results are a self-consistent view of the current state of the ZEV transition.

2

RATING FRAMEWORK

2 RATING FRAMEWORK

2.1 Scope of the rating

This rating focuses on the production and sale of LDVs. Its analysis is based on data developed for auto manufacturers in the six largest LDV markets in 2022: China, the United States, Europe, Japan, India, and the Republic of Korea. These are the top five markets in terms of LDV sales in 2022 and Korea, which was the seventh largest in sales and the fifth largest in terms of vehicle production. These six markets together have accounted for about 73% of global LDV sales in recent years (MarkLines, 2023).

We selected the top 20 auto manufacturers in the world based on their global 2022 LDV sales. For this rating, manufacturer means the controlling corporate entity. An entity might control multiple automotive brands. For joint ventures in China, manufacturers headquartered outside of China collaborate with a China-headquartered counterpart under a technology-sharing agreement; in these cases, we distinguish between vehicles that are manufactured under non-domestic or domestic brands and then count the corresponding sales toward the non-domestic or domestic controlling corporate entity accordingly.

Figure 1 shows the top 20 manufacturers and their 2022 global LDV sales, with color-coding representing sales in the six major regions and an additional category for sales in the rest of the world. These manufacturers were about 90% of all LDV sales in the six major markets; their sales in these six markets were the vast majority of their global LDV sales. The region after each automaker's name indicates the location where it is headquartered. Five are headquartered in China, five in Japan, five in Europe, three in the United States, one in the Republic of Korea, and one in India. Most of the 20 manufacturers sell in multiple regions.

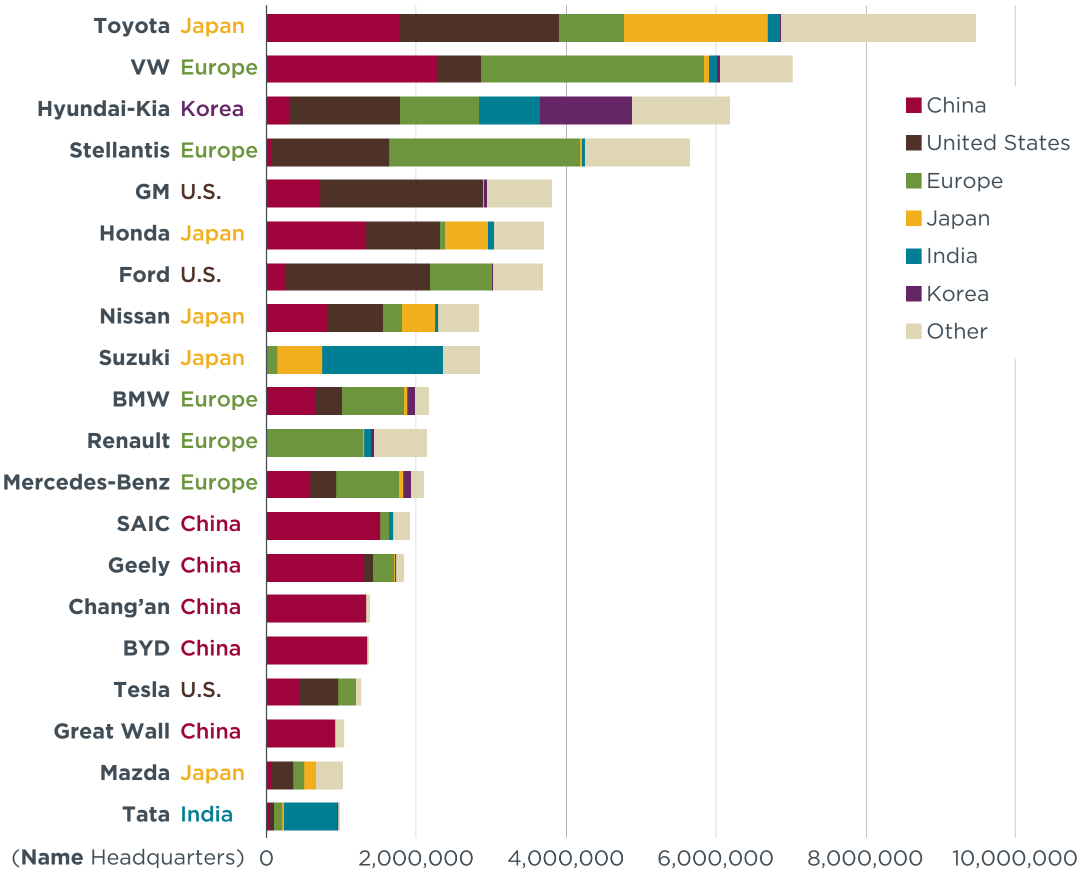

Figure 1. 2022 light-duty vehicle sales by the top 20 manufacturers in the six major markets.

We evaluate manufacturers based on their sales, actions, and strategies in the six major markets. Vehicle-related analyses are based on new light-duty sales in 2022; forward-looking strategy and actions-related analyses are based on information collected through the end of 2022.[1]

1 Some information was collected in 2023, to verify the feedback we received from automakers; nonetheless, all information reflects the state of the automakers only through 2022.

2.2 Evaluation structure

We designed the rating around three pillars, each made up of different metrics. There are 10 metrics in total. Together, they reflect the latest efforts toward and potential for a full ZEV transition. Figure 2 provides an overview of the three pillars (market dominance, technology performance, and strategic vision) and 10 metrics. The area for each metric in the figure represents its contribution to the final rating.

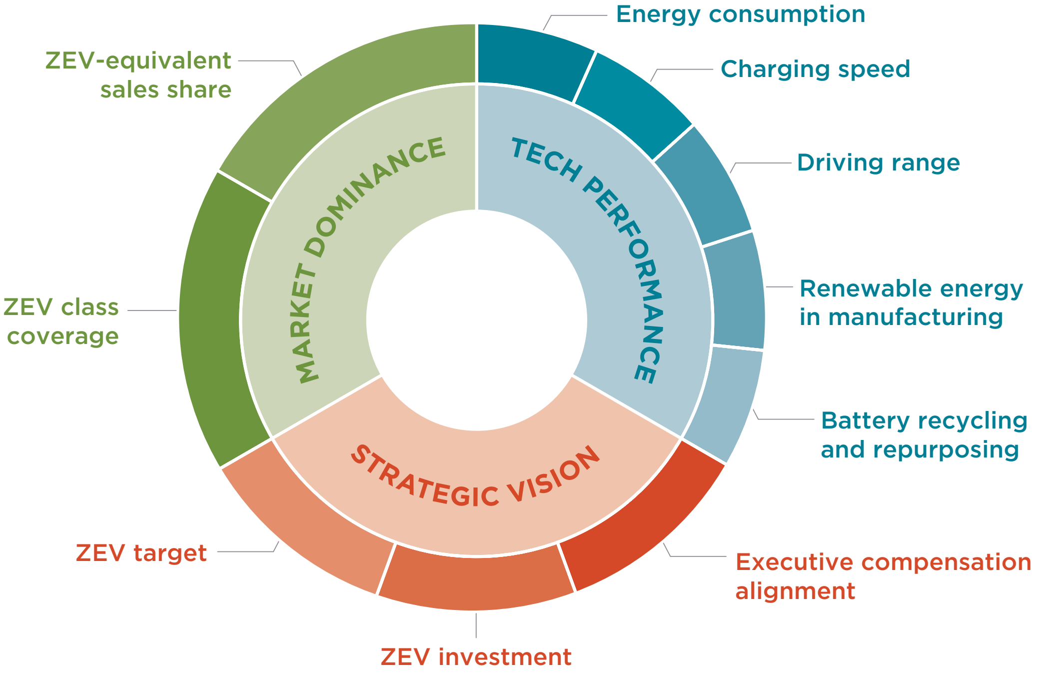

Figure 2. Overview of the structure of ICCT's Global Auto Rating.

Market dominance reflects the progress each manufacturer has made in its transition to ZEVs. It consists of two metrics:

- *ZEV-equivalent sales share* is the fraction of each manufacturer's LDV sales that are BEVs, FCEVs, and PHEVs. Each PHEV was discounted as a percentage of a ZEV based on the real-world electric drive share of PHEVs, estimated from recent studies.
- *ZEV class coverage* reflects the share of eight LDV classes, ranging from mini/subcompact car to light truck, that are covered by model offerings from each manufacturer.

Technology performance consists of five metrics, three important to consumer experience and two concerned with reducing upstream emissions, which is an important part of decarbonizing the automotive industry. They are:

- *Energy consumption* is the sales-weighted average of certified energy consumption of BEVs sold by each manufacturer, normalized to the same test cycle and in watt-hours per kilometer (Wh/km).
- *Charging speed* is the maximum average charging speed of BEVs sold by a manufacturer, in kilowatts (kW).
- *Driving range* is the sales-weighted average of certified driving range of ZEVs sold by a manufacturer, normalized to the same test cycle and in kilometers (km).

- *Renewable energy in manufacturing* reflects efforts an automaker has made to move to 100% renewable electricity in vehicle assembly and battery manufacturing.
- *Battery recycling and repurposing* reflects whether manufacturers have begun pilot projects or collaborations in battery recycling and reuse.

Strategic vision reflects the vision and commitment of each manufacturer in the ZEV transition. It consists of three metrics:

- *ZEV target* is based on each company's stated ZEV sales share targets and dates, and their degree of alignment with the ZEV sales shares needed to keep global warming below 2 °C.
- *ZEV investment* includes total announced investment in ZEV and battery production sites, charging infrastructure, and ZEV research and development (R&D), relative to an automaker's size.
- *Executive compensation alignment* reflects the extent to which an automaker's top executive's pay is tied to EV development.

We award manufacturers points according to their performance on each metric. The highest possible score in each metric is 100; the lowest is zero. Although some metrics have the absolute best and worst performance by nature, such as a ZEV sales share of 100% (best) and 0% (worst), metrics like energy consumption, charging speed, and driving range have no natural absolute best or worst. Therefore, to create an evaluation mechanism that applies the same to all metrics, we set the bottom score to zero and assigned the top performer for each metric a score of 100. We applied Equation (1), below, to calculate the final score for each manufacturer for each metric:

$$\textit{Metric score (0 to 100 scale)} = \frac{Points - Points_{min}}{Points_{max} - Points_{min}} \times 100 \qquad (1)$$

Where

Points is the number of points for the metric for a given manufacturer;

$Points_{min}$ is the lowest number of points across all manufacturers; and

$Points_{max}$ is the highest number of points among all manufacturers.

Scores are calculated for each of the three pillars and each pillar score is calculated as the average of the metric scores within that pillar. If an automaker has "N/A" for a metric, we average the scores of the other metrics to get the pillar score.[2] The final rating is calculated as the average of the three pillar scores. While all averages are done without rounding, the results reported are rounded to the nearest integer. We assign the same weight to the three pillars in the final rating, because they are equally important. Because there are different numbers of metrics within each pillar, the comparative weighting of individual metrics is the same within each pillar, but different from the individual metrics in other pillars. This is inherent in the design of our evaluation.

2.3 Data sources and process

Five of the metrics assessed in this rating are at the vehicle level and the other five are at the manufacturer level. Vehicle-level metrics are ZEV-equivalent sales share, ZEV class coverage, energy consumption, charging speed, and driving range.

2 Suzuki got N/A for the energy consumption, charging speed, and driving range metrics, because it did not sell any ZEVs in 2022. It was the only automaker to receive N/A for any metric.

Manufacturer-level metrics are ZEV target, ZEV investment, executive compensation alignment, renewable energy in manufacturing, and battery recycling. Data sources are described below.

For vehicle-level data, we developed a database that includes all new LDVs sold in 2022 by the manufacturers in the six vehicle markets. We obtained vehicle data from multiple sales databases to maximize data coverage and accuracy. Data regarding vehicle sales and vehicle power train type were derived from four sources for new vehicles sold in 2022. This includes U.S., Korea, and Japan data from MarkLines (MarkLines, 2022); Europe data from Dataforce (Dataforce, 2022), including vehicle sales in the European Union, EFTA (European Free Trade Association) member states, and the United Kingdom; India data from Segment Y (Segment Y, 2022); and China data from ZEDATA (ZEDATA, 2022). Data on the specifications (gross weight and curb weight, gross and net battery capacity, energy consumption, driving range, and charging time) of each model were collected from specification brochures on manufacturers' official websites and from major EV information hubs including ev-database.org, evspecifications.com, and ev-volumes.com for European and U.S. models, and yiche.com and autohome.com for Chinese models. Variations in the level of detail and focus, including things like included data fields, among the various datasets required substantial processing to develop a comprehensive set of globally consistent data. Appendix A describes the methodology behind the creation of this database.

For manufacturer-specific actions, information about ZEV targets, use of renewable energy in manufacturing, and battery recycling and repurposing was primarily sourced from the manufacturers' latest annual sustainability reports.[3] This was supplemented with press releases, media articles, and public announcements collected through the end of 2022, to capture any developments between when the sustainability report was published and the end of the year. Some automakers provided feedback to our input information by referring to their sustainability reports published in 2023. We incorporated that information into this rating as long as it reflected the automakers' efforts in 2022. The data used to assess manufacturers' investments in ZEVs was obtained from Atlas Public Policy's EV Hub (Atlas Public Policy, 2022). The information regarding the mechanism behind and the elements used in determining the compensation for each company's chief executive was compiled by Valens Research specifically for this rating. The information was extracted from the proxy statements and other public filings of each manufacturer. Detailed information on the data sources is in the methodology section for each individual metric. The complete list of annual sustainability reports and supplementary sources reviewed for this analysis is in Appendix A.

Most of the top 20 manufacturers operate in multiple major markets, and practices and ambitions can differ across regions. For example, some manufacturers have adopted 100% renewable electricity in manufacturing in Europe, but not in other regions. The same manufacturer might also announce different ZEV targets and ICEV phase-out dates for Europe, the United States, and the other regions. To account for such differences, we collected manufacturers' global and regional strategies and implementation actions from the sources described above. Whenever there were divergences in regional practices, we calculated the global average performance metrics weighted by the vehicle sales in the corresponding regional markets.

3 Sometimes annual sustainability reports were identified by the companies as an environmental report, climate report, or ESG report. For simplicity, we refer to all of these as "annual sustainability report" throughout this report.

Additionally, some subsidiary marques have separate sustainability reports that set different goals from the parent company. For example, Volvo has separate sustainability reports and different ZEV targets than its parent company, Geely. In this case, we collected information about strategies and implementation for both the subsidiary company and the parent company and calculated the average performance metrics weighted by the sales of the different marques.

To ensure the accuracy and timeliness of the manufacturer-specific information used for this rating, we asked all 20 automakers to review the input data and information used for evaluating manufacturer-specific actions and commitments. We did not disclose the evaluation framework or evaluation methodology in our communication with automakers. We received feedback from 11 automakers: BMW, BYD, Ford, GM, Great Wall, Mercedes-Benz, Renault, Stellantis, Tata, Tesla, and VW. When automakers disagreed with our information, they generally provided revised or updated data with or without citing sources. We reinvestigated to verify all information before using it for the analysis. The final manufacturer-specific information applies to the evaluation of five metrics: renewable energy use, battery recycling and repurposing, ZEV target, ZEV investment, and executive compensation structure. The analysis of the other five metrics was based on vehicle-specific data from either proprietary data sources or open sources; we did not ask automakers for feedback on that data.

3

MARKET DOMINANCE

3 MARKET DOMINANCE

3.1 ZEV-equivalent sales share

The ZEV-equivalent sales share, which represents the share of an automaker's total LDV sales that are ZEVs, is the most direct measure of progress in the ZEV transition. The ZEV-equivalent sales share is the sum of a manufacturer's ZEV share and the discounted PHEV share. ZEVs are BEVs with no additional power source or FCEVs. PHEVs are hybrid vehicles equipped with an internal combustion engine, an electric motor, and a battery that can be charged externally. They are considered partial ZEVs because they can be driven for a period with zero tailpipe carbon dioxide (CO_2) emissions. The discount factors for PHEVs in this evaluation are based on real-world statistics. Ideally, the ZEV-equivalent sales share would be 100%, indicating that a manufacturer produces and sells only ZEVs.

METHODOLOGY

Vehicle sales data is from the compiled vehicle sales database explained in Section 2.3, which reflects all new LDVs sold in the six major markets in 2022.

While each BEV or FCEV sold counts as one ZEV, we discount a portion of PHEV sales using a factor based on real-world electric drive share (i.e., the portion of kilometers driven on electricity). The discount factors reflect the non-electric driving share. Recent research estimated that the real-world electric drive share of PHEVs in the United States is 25–56% lower than what is indicated in the U.S. Environmental Protection Agency's (EPA) labeling program (Isenstadt et al., 2022). Studies also found lower real-world electric drive share in Europe and China (Plötz et al., 2020; Plötz et al., 2022). Using the real-world electric drive share to discount PHEV sales share better reflects the more limited climate benefits PHEVs deliver compared to BEVs and FCEVs.

The PHEV discount factor depends on the electric driving range of the model. Real-world data shows that, in general, the longer the all-electric range of a PHEV, the larger the share of all-electric, zero-tailpipe-emissions driving. For each PHEV model, the discount factor we apply to determine the ZEV-equivalent share is calculated by an equation that relates a model's charge-depleting range to its real-world electric drive share. Details of this calculation are presented in Appendix C.1. (The sources of PHEV charge-depleting range data were described in Section 2.3.) The discount factors for PHEV models range from 28%–94%; the sales-weighted average is 68%.

The total ZEV-equivalent sales share is the sum of the ZEV share and the discounted PHEV share, ranging from 0%–100%. The manufacturer with the highest ZEV-equivalent sales share receives a score of 100 . The manufacturer with the lowest ZEV-equivalent sales share receives a score of zero. Other manufacturers are scored based on their relative metric points compared with the best and worst performers and receive a score between zero and 100 (see Equation [1]).

RESULTS

As expected, there were large variations in manufacturer sales shares in 2022. Some legacy manufacturers (i.e., manufacturers that have been producing ICEVs), including BYD and SAIC, have made noticeable advances in bringing ZEVs to market. Figure 3 summarizes the vehicle sales shares of LDVs by manufacturer in 2022. On the right side of the figure, the blue bars indicate the sales share of BEVs and FCEVs. The yellow bars, including the part with a pattern, indicate the actual PHEV sales share. The solid yellow bars indicate the discounted PHEV sales share after accounting for their real-world electric drive share. On the left side of the figure, the grey bars indicate sales of ICEVs. The final ratings of this metric for each automaker are listed to the right of the bars. Details of the ZEV and PHEV sales shares by manufacturer and details of the ZEV-equivalent shares across the six major markets are presented in Table B1 in Appendix B.

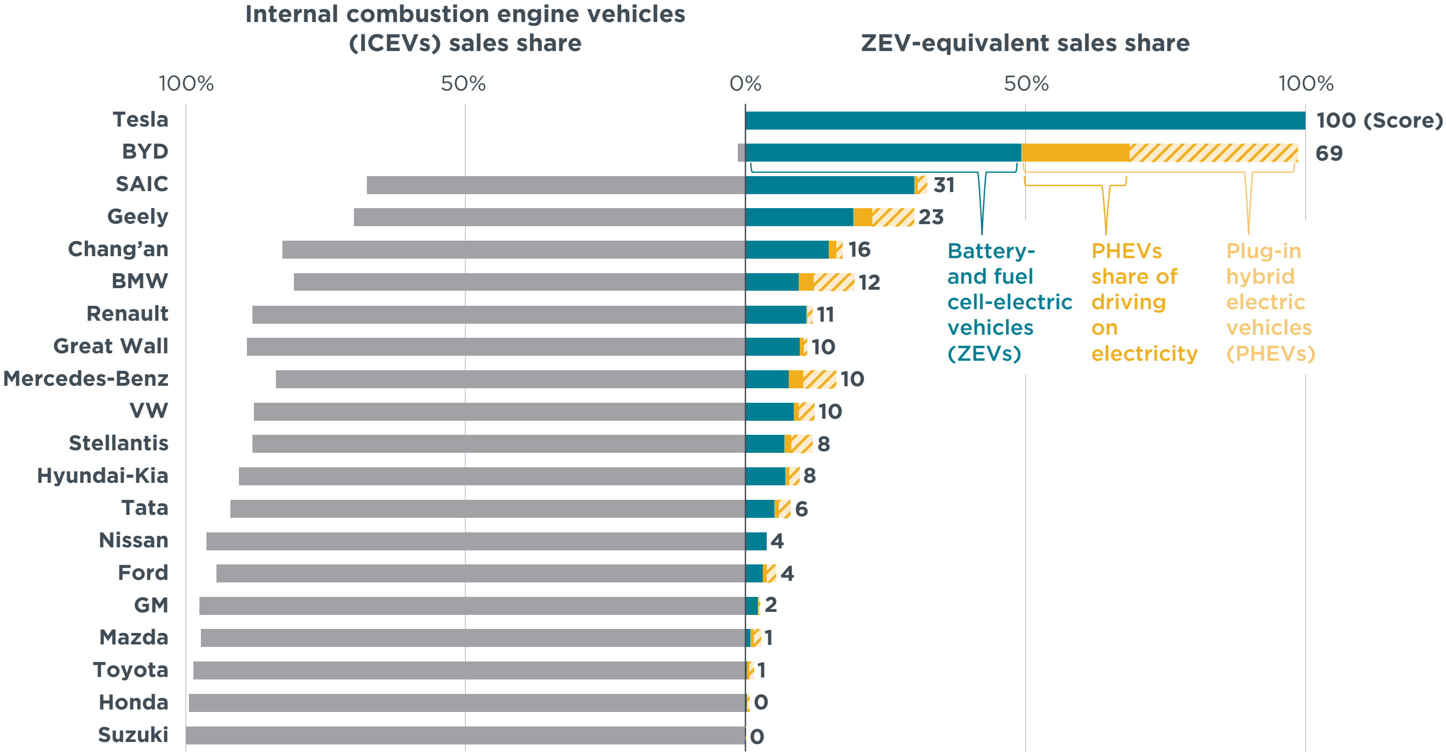

Figure 3. ZEV and PHEV sales share by manufacturer in 2022 and rating for the ZEV-equivalent sales share metric.

Most manufacturers' ZEV-equivalent sales are driven by BEV sales. BYD is the only manufacturer with a considerable PHEV share (49%). FCEV sales were minimal, 0.2% of all ZEV sales by all 20 manufacturers; 97% of those sales were by Hyundai-Kia and Toyota; the remaining sales were split between Honda, SAIC, and BMW.

Tesla leads on this metric with a 100% ZEV-equivalent sales share, because it only produces BEVs. BYD, which made the transition to only producing BEVs and PHEVs in March 2022, follows closely with a 69% ZEV-equivalent sales share. The other four manufacturers headquartered in China have ZEV-equivalent shares ranging from 10%–31%, with most sales coming from the Chinese market. Geely's high ZEV-equivalent share in Europe is from its Volvo subsidiary. Manufacturers headquartered in Europe have ZEV-equivalent shares between 8–12% and have significantly higher ZEV-equivalent sales shares in Europe than in other markets. The two manufacturers headquartered in the United States, Ford and GM, have relatively low ZEV-equivalent shares, each below 5%. Manufacturers headquartered in Japan also performed poorly in this metric, with ZEV-equivalent shares ranging from 0.03%–4%. Suzuki received a score of zero because it has the lowest ZEV-equivalent sales, a combination of zero ZEV sales and a PHEV sales share of 0.1%.

3.2 Class coverage

Automakers often sell a variety of models across many vehicle classes or segments to attract a broad range of customers. Consumers use vehicles to meet a variety of needs. Their requirements when selecting a vehicle for purchase thus vary; because of this, they need a variety of models from which to choose. The class coverage metric evaluates the range and diversity of BEV and FCEV models offered by manufacturers and how well they cater to different market segments. Manufacturers with broader class coverage have invested in vehicle technology and production platforms to serve different submarkets. This wider range of coverage could give manufacturers an advantage when they seek to grow, because they will have access to a larger customer base. Having a variety of ZEV models for sale also supports the overall transition, as it increases consumer choice. As this metric reflects manufacturers' efforts toward a zero-tailpipe-emissions future, PHEV models are excluded.

METHODOLOGY

There is no universal definition for vehicle classes. Consequently, combining data from major vehicle markets results in myriad inconsistent vehicle classifications. To address this, we use a simplified classification system based on vehicle length for passenger cars (PCs) and curb weight for light commercial vehicles (LCVs) and apply it to the ZEV data from all six markets. We classify passenger cars into five classes (mini/subcompact car, compact car, midsize car, large car, and SUV/MPV) and LCVs into three classes (small, medium, and large), for a total of eight defined classes. The length thresholds for PC classification are based on EV-Volumes' global segment classification (EV-Volumes, 2023), and curb weight thresholds for LCV classification are based on the EU N1 subclasses standard (Vermeulen et al., 2012). We combine mini PCs with the subcompact class to reflect the model availability in the smaller PC segment. Detailed weight thresholds are listed in Appendix C.

Since batteries are heavy, BEVs can weigh more than with their ICEV counterparts. Because the EU curb weight classifications were initially designed for ICEVs, directly mapping BEVs into their corresponding weight classes might lead to inaccurate categorization. For this reason, we adjust the curb weight of BEVs to be comparable with their ICEV equivalents for LCV classification. To determine the appropriate adjustment factor, we calculated the ratio of curb weight of ten popular ICEV models and their ZEV counterparts of nearly identical size. The average curb weight ratio was found to be 0.83. This average ratio was used as a discount factor to estimate the ICEV-equivalent curb weight of each BEV model. This method proved effective in reasonably estimating ICEV-equivalent curb weights for ZEV models across a wide range of curb weights (see Appendix C.2). Then we compared the adjusted curb weight against thresholds from the EU N1 subclasses standard to determine the vehicle class of each LCV BEV model.

We consider a defined class to be covered by a manufacturer if there were sales of at least one ZEV model within said class. The coverage rate is the ratio of the total number of classes covered by the manufacturer and the total number of classes considered, eight. For instance, if the ZEV models sold by a manufacturer cover four out of the eight classes, we assign a score of 4/8 = 50% for this metric.

Lastly, we convert the coverage rate to the 100-point system. The manufacturer with the highest class coverage rate receives a score of 100 and the manufacturer with the lowest class coverage rate receives a score of zero. Other manufacturers are scored using Equation (1).

RESULTS

Almost all manufacturers offer ZEV models in the SUV/MPV segment; the one exception is Suzuki, which offered only plug-in hybrid SUVs and did not have any ZEV models in any class. Several manufacturers sold a wide variety of BEV models that cover more than half of all classes. Table 1 summarizes ZEV model availability across all eight vehicle classes and the final score for this metric. A vehicle icon is shown where a manufacturer offers a model for each class. The final score is shown in the rightmost column.

Table 1. ZEV (BEV and FCEV) model class coverage for each manufacturer

	PC class					LCV class			
OEM	Mini/ Subcompact	Compact	Midsize	Large	SUV/MPV	Small	Medium	Large	Score
SAIC	✓	✓	✓	✓	✓	✓	✓	✓	100
VW	✓	✓	✓	✓	✓		✓	✓	88
Chang'an	✓	✓	✓	✓	✓	✓	✓		88
Stellantis	✓	✓	✓		✓	✓	✓	✓	88
Geely	✓		✓	✓	✓	✓	✓	✓	88
BYD	✓	✓	✓	✓	✓		✓	✓	88
Renault	✓	✓	✓		✓		✓	✓	75
Great Wall	✓	✓		✓	✓		✓	✓	75
Toyota	✓			✓	✓		✓	✓	63
Hyundai-Kia		✓	✓	✓	✓		✓		63
Mercedes-Benz	✓			✓	✓		✓	✓	63
Nissan		✓	✓		✓		✓	✓	63
BMW	✓		✓	✓	✓				50
Honda	✓		✓		✓				38
GM			✓		✓			✓	38
Tesla			✓	✓	✓				38
Tata	✓				✓				25
Ford					✓		✓		25
Mazda					✓				13
Suzuki									0

Manufacturers headquartered in China are leading in class coverage. SAIC's score is 100, because it has full coverage across all eight classes. Chang'an, Geely, BYD, and Great Wall all have offerings in both PC and LCV segments, and their resulting coverage rates are between 75%–88%. Manufacturers headquartered in Europe performed above average: VW, Stellantis, and Renault rank high with class coverage rates between 75%–88%. These automakers offer LCV models like the Volkswagen e-Transporter, the Peugeot e-Expert, and the Renault Kangoo E-Tech. Mercedes-Benz does not offer mid-class zero-emission cars. BMW does not offer ZEV products in the LCV segment and has a lower class coverage rate of 50%. Honda, GM, Tesla, Tata, Ford, and Mazda performed below average with coverage rates between 13%–38%. GM and Tesla focused mostly on passenger car ZEV models, whereas Ford's ZEV products are only in two heavier vehicle classes, SUV and medium LCV. Mazda's only ZEV offerings are the MX-30 and CX-30 (the latter only available in China), both of which are SUVs, and its class coverage rate is 13%. Suzuki gets a score of zero for not having any ZEV models in 2022.

There are factors that this metric does not capture equally across all automakers. Tesla's offerings are in a limited range of classes, but it already sells exclusively BEVs. Other manufacturers have multiple ZEV models at a variety of price points, but within only a few classes. While these manufacturers might thus be better positioned to sell within those classes today, their customer base is more limited. Additionally, the popularity of PCs and LCVs varies across the six major markets, and some automakers might offer models in certain classes because of the popularity of those classes in a certain market. Still, this analysis is global in scope and most of the automakers assessed have global operations. Therefore, the more classes an automaker covers, the more they are contributing to the global ZEV transition across all vehicle classes. Lastly, this metric does not incorporate the number of ZEV models a manufacturer offers in each class or the prices of the models, even though both might impact consumer purchase decisions.

4

TECHNOLOGY PERFORMANCE

4 TECHNOLOGY PERFORMANCE

4.1 Energy consumption

The energy consumption metric evaluates the sales-weighted average certified energy consumption of BEVs sold by each manufacturer. Energy consumption measures the amount of energy consumed per distance traveled. For vehicles with the same battery size, the vehicle that consumes less energy can drive longer distances per charge. BEVs that consume less energy help limit the upstream emissions from vehicle use and consume less electricity from renewables. Vehicles that consume less energy also reduce energy costs for consumers.

METHODOLOGY

Energy consumption is reported by manufacturers according to the regulations in place in the six markets. For each BEV model in our database, we collected the certified energy consumption in Wh/km under the Worldwide harmonized Light vehicles Test Procedure (WLTP). FCEVs are excluded from the calculation of fleet average energy consumption because they operate differently than BEVs. Compared to the direct use of electricity from batteries in BEVs, which is more than 70% efficient, the process of generating electricity from hydrogen through a fuel cell is only approximately 50% efficient. This causes FCEVs to consume almost twice as much energy as comparable BEVs. Thus, this evaluation focuses on BEVs, and recall that these were 99.8% of total 2022 ZEV sales of the 20 automakers.

Energy consumption data is sourced from the certification values that were measured using different test cycles, such as the WLTP, New European Driving Cycle test cycle (NEDC), China Light-Duty Vehicle Test Cycle (CLTC), and the U.S. label value used by the U.S. EPA. Energy consumption values from the different test cycles are standardized to WLTP-equivalent values by using conversion factors. We apply a multiplier of 1.15 to convert the NEDC or CLTC energy consumption to its equivalent value under the WLTP test cycle. Similarly, a discount factor of 1.2 is used to convert the U.S. label values to their equivalent values under the WLTP (Yoney, 2022). These conversions allow for a consistent comparison of energy consumption across models.

We adjust the energy consumption of each BEV model to account for the weight differences of vehicles, as physical differences inherently affect energy consumption. The impact is shown in our analysis: Regressing energy consumption on curb weight using all BEV models in our database showed a strong correlation between the two variables (see Appendix C.3 for details). BEVs are sold in different vehicle classes across manufacturers. For example, 100% of BEVs sold by Ford were either SUVs or LCVs with an average curb weight of 2,821 kg. The data also show that more than 90% of BEVs sold by SAIC were subcompact or compact cars that had an average curb weight of 1,019 kg. Thus, the adjustment allows manufacturers to be compared independent of size.

For the weight adjustment, we benchmark the energy consumption of each model to the same baseline weight of 1,773 kg, which is the sales-weighted average curb weight of all sales of new ZEVs sold by the top 20 automakers in 2022 in the six markets. The regression result shows that, on average, each kilogram increase in curb weight is correlated with a 0.056 Wh/km increase in energy consumption. This finding is similar to a previous study, Weiss et al. (2020), which investigated 218 electric passenger cars from China, Norway, and the United States, and found a similar correlation of 0.06

$Wh{\cdot}km^{-1}{\cdot}kg^{-1}$. We use 0.056 $Wh{\cdot}km^{-1}{\cdot}kg^{-1}$ as the adjustment rate to calculate the energy consumption adjustment needed based on the curb weight difference in kilograms between each model and the baseline weight. For a model that is 100 kg heavier than the baseline of 1,773 kg, we adjust the energy consumption downward by 100*0.056 = 5.6 Wh/km to normalize the energy consumption of this model.

With the adjusted energy consumption of each model, we calculate the average energy consumption for each manufacturer, weighted by the total sales of each model produced by the manufacturer across the six major markets. The adjusted energy consumption values are then converted to a 100-point score using the manufacturers with the lowest energy consumption as the benchmark. The manufacturer with the lowest sales-weighted average energy consumption receives a score of 100 and the manufacturer with the highest sales-weighted average energy consumption receives a score of zero. Other manufacturers are scored based on their relative metric points compared with the best and worst performers and receive a score between zero and 100 (Equation [1]).

The energy consumption values used for the analysis are certified values from the vehicle type-approval process. We considered using the real-world energy consumption of ZEVs because energy consumption in the real-world can sometimes vary significantly from type-approval values. Komnos et al. (2022) found that the real-world energy consumption for battery electric cars can be 4.5%–23.9% higher than the certified values. Recent work from ICCT, Jin et al. (2023), analyzed data from 140,000 vehicles, 10 high-selling BEV PC models in five Chinese cities; the energy consumption was found to be 18% higher than type-approval values on average, but there were clear differences in the gap between real-world and type-approval values by model, and the range was from 0% to 30%. Note, also, that the real-world energy consumption of a vehicle is impacted by external factors such as the ambient temperature and traffic conditions (Al-Wreikat et al., 2021). Jin et al. (2023) found that driving BEV PCs in "cold" (≤ 0 °C) and "hot" (30 °C–35 °C) conditions could, on average, increase energy consumption by approximately 39% and 11%, respectively, compared to the certified values. Therefore, comparing the real-world performance of BEVs can be different from comparing the performance during laboratory testing, depending on the functionality of the model and where and how it is driven. However, there are no ideal real-world data sources that cover the wide range of models and brands in this analysis. In the absence of a high-quality real-world database, we use type approval data. This also reflects the information given to consumers via the official specifications of a manufacturer's offerings.

RESULTS

Similar to the variance in fleet-average fuel consumption of ICEVs across manufacturers, we see a noticeable variance in BEV energy consumption. The energy consumption of the lowest-scoring automaker, Mazda, is about 38% higher than the highest-scoring automaker, Tesla. Figure 4 illustrates the average energy consumption of BEVs after the adjustment by vehicle curb weight and the score for this metric by manufacturer. Shorter bars illustrate less average energy consumption, and this translated into a higher metric score. The underlying data of the average energy consumption of BEVs before and after the adjustment by weight is in Appendix B, Table B2.

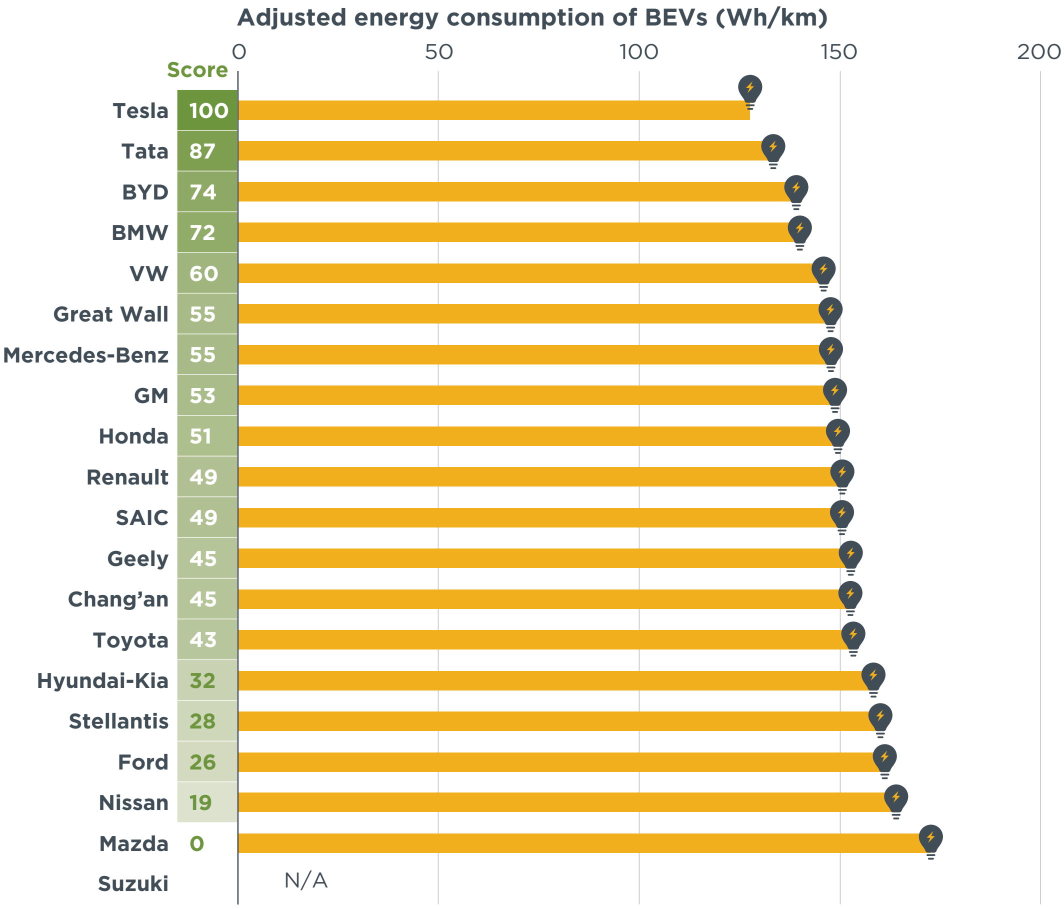

Figure 4. Average energy consumption of BEVs and metric scores by manufacturer.

Tesla and Tata lead on this metric with average adjusted energy consumption of 124 Wh/km and 130 Wh/km, respectively. Other automakers have an average adjusted energy consumption value between 136–171 Wh/km. Mazda has the highest average adjusted energy consumption value of 171 Wh/km and thus received a score of zero. Suzuki does not have a score for this metric, because it did not sell any BEVs in 2022.

4.2 Charging speed

Concerns about the length of charging time, especially when charging during long-distance travel, could significantly impact consumer adoption of BEVs and their willingness to purchase a vehicle (Li et al., 2020).

Although some DC fast chargers can deliver power up to 350 kW, there is a large difference in the maximum charging speed that can be accepted and the average charging speed across BEV models. For example, the Hyundai IONIQ 5 supports 350 kW DC charging and has an average charging speed of 169.4 kW; it takes 18 minutes to charge its 72.6 kWh batteries from 10% to 80%. Meanwhile, the Chang'an Lumin BEV, the second best-selling model from Chang'an, has a comparatively weak 2 kW onboard charger and requires 6.5 hours to fully charge its 13 kWh variant and 8.8 hours to fully charge its 28 kWh variant. Given the importance of charging time in BEV adoption, this metric can provide insight into the attractiveness of BEV models' charging options.

METHODOLOGY

For this metric we calculate the sales-weighted average charging speed of BEV models sold by each manufacturer. Similar to energy consumption, we exclude FCEVs because of the difference in the technology and refueling processes. To calculate the charging speed for each BEV model, information on net battery capacity and charging time of all compatible chargers is collected and compiled into a ZEV-specification database (see Section 2.3). For models for which no data on net battery capacity is available, a multiplier of 0.95 is applied to the gross battery capacity, which is estimated from regression analysis using 228 models with both net and gross battery capacity information available. The regression analysis uses an OLS (ordinary least squares) model to regress the net battery capacity on gross battery capacity.

Data on the charging speed of BEV models is typically provided for normal chargers and fast chargers. Normal chargers are Level 2 home, workplace, and public chargers that typically have a power rating between 3 kW and 22 kW from alternating current (AC; Rajon Bernard et al., 2021). Fast chargers are typically direct current (DC) and include 50 kW to 350 kW chargers. In this analysis, charger type definitions follow the European Court of Auditors (2021) and details are in Appendix C.4. All BEV models accept normal chargers, but only some BEV models are capable of DC fast charging and the maximum charging speed accepted at DC fast chargers varies by model.

For BEV normal or Level 2 charging, each model's average charging speed is calculated by dividing its net battery capacity by the amount of time needed to charge from 0% to 100%. For BEV fast charging, the average charging speed is based on 70% of the net battery capacity and the time needed to charge the battery from 10% to 80%, as this is typically the measurement provided by the manufacturer for fast charging. This range is also more representative of the real-world use of fast chargers, as most drivers fast charge between 20% and 80% state of charge, and because charging speed typically slows down significantly above 80% (Whaling, 2022). As the battery approaches full capacity using a fast charger, the battery management system slows the charging rate to avoid overcharging and prolong the battery's life. Therefore, we define the average charging speed for fast charging as the net battery capacity in kWh multiplied by the charged percentages of 70% divided by the charging time in hours to charge from 10% to 80%.

If a model has multiple charging options, we select the average charging speed from the fastest option it can take. Then we average the maximum average charging speed of all BEV models of each manufacturer weighted by the sales of the models. The average charging speed values are converted to a 100-point score following Equation (1). The manufacturer with the fastest charging speed receives a score of 100 and the manufacturer with the slowest receives a score of zero. Other manufacturers are scored based on their relative speed compared with the best and worst performers and receive a score between zero and 100.

We also explored the feasibility of rating this metric based on driving range per unit of charging time (e.g., km/min), because it is another common approach for measuring charging speed and it might be easier for a broad audience to comprehend. However, this approach unavoidably considers energy consumption in the calculation, and that is a separate, key metric of this report. We determined that the overlap was unacceptable and thus opted to measure this metric using kW.

RESULTS

Automakers show significant variations in sales-weighted average charging speed, with the highest-scoring automaker 8.6 times faster than the lowest-scoring automaker. Figure 5 shows the final score for each manufacturer and their average charging speed. Manufacturers that sell a higher share of BEVs incapable of fast charging, such as SAIC and Chang'an, have much lower average charging speeds compared with the others. Table B3 in Appendix B details the sales-weighted average charging speeds for each automaker for BEVs that do not support fast charging and for BEVs that support fast charging, and includes the sales share of each BEV group for each manufacturer.

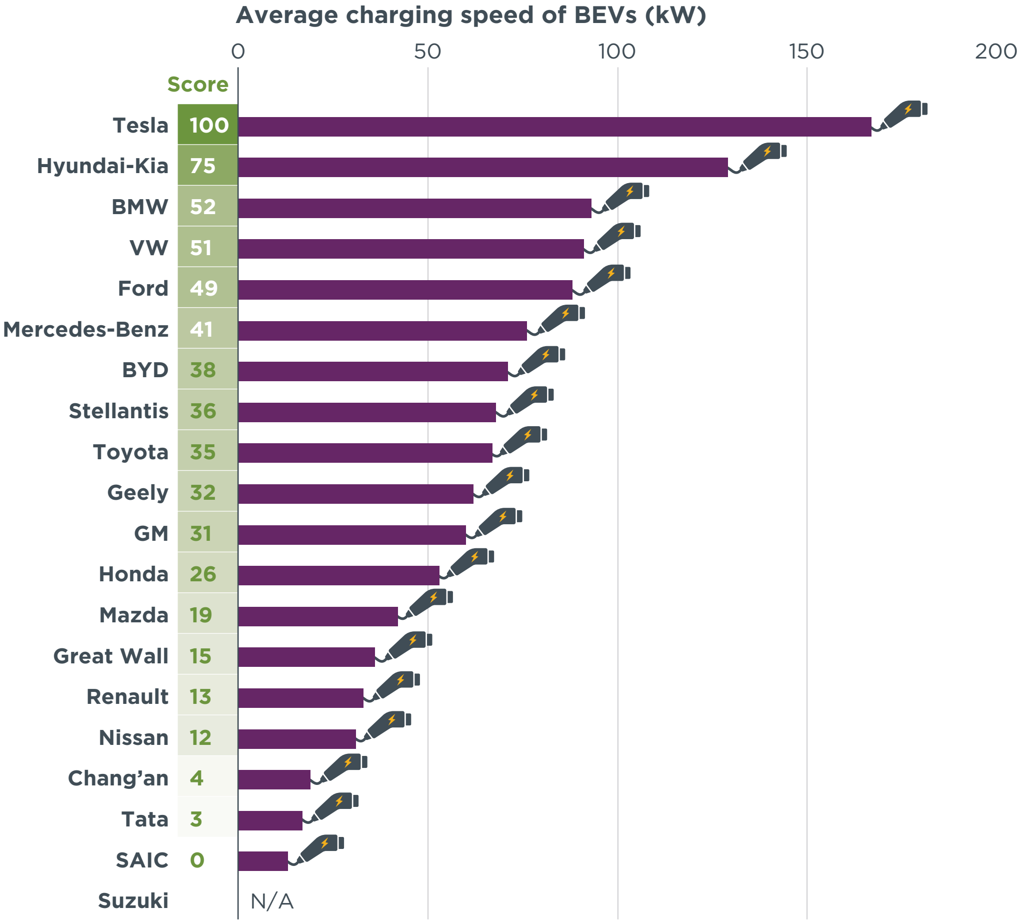

Figure 5. Average charging speed and metric score by manufacturer.

Tesla tops all manufacturers in charging speed for fast charging with an average charging speed of 172 kW. Hyundai-Kia follows closely with an average speed of 134 kW. Both Tesla and Hyundai-Kia have several high-selling models that are among the fastest-charging BEVs available, including the Tesla Model X, Hyundai IONIQ 5, and Kia EV6. Most of the manufacturers headquartered in Europe, two manufacturers headquartered in the United States, and BYD, Toyota, and Geely have average charging speeds ranging from 65 kW to 98 kW. Renault lags behind its Europe-headquartered peers with an average charging speed of 38 kW; this is due to a lack of fast-charging capabilities in 17% of its BEV sales and the low average charging speed of its best-selling model.

Chang'an, Tata, and SAIC ranked well below average for charging speed, as some of their high-selling BEVs are lower-to-mid price BEVs that only support home charging.

SAIC had the lowest score, with an average charging speed of 18 kW; this was mainly due to the limited charging capability of its best-selling model, the Hongguang Mini, which accounts for 64% of its BEV sales and has a 1.5 kW charger that takes 7 hours to fully charge its 10.5 kWh battery. Suzuki does not have a score for this metric because it did not sell any BEVs in 2022.

4.3 Driving range

Driving range is another metric valued by consumers, as longer range expands vehicle functionality and minimizes range anxiety. It is a key factor in the convenience of BEVs for consumers. Automakers offering only shorter-range BEVs might struggle to keep up in the ZEV transition, as research suggests that consumers might be less likely to switch to EVs if they have short ranges (Stockkamp et al., 2021). Another sign of the importance of driving range is that the California Air Resources Board (CARB) has set minimum range requirements for BEVs that can count toward the ZEV targets in its Advanced Clean Cars II regulation (California Air Resources Board, 2022). Offering higher-range vehicles could encourage faster ZEV uptake, deliver more climate benefits, and make automakers more competitive.

While consumers generally prefer a longer driving range, it comes with costs, both financial and environmental. Larger batteries are needed to provide range, and this increases vehicle weight. Heavier vehicles require more energy to move them, and the resulting increased electricity consumption increases both recharging costs for the consumer and GHG emissions from upstream electricity production while fossil fuels are still used. There are costs for the manufacturer, as well, because greater quantities of input materials such as lithium and other critical minerals are necessary to build the larger batteries. Designing BEVs with longer ranges can thus expose manufacturers to price swings in lithium and other minerals more so than making short-range vehicles. Additionally, because battery production and mining for key minerals are major sources of the overall GHG emissions in BEV manufacturing, making longer-range vehicles increases those emissions as long as fossil fuels are still used in upstream mining and manufacturing.

While keeping in mind all of these realities of longer-range BEVs, we include this metric in our assessment because of its importance in attracting a wide consumer base. Additionally, as the vehicle market is still dominated by ICEVs, larger-battery BEVs still provide environmental benefits.

METHODOLOGY

The sales-weighted average driving range of all ZEVs sold by each manufacturer is calculated. We first collect the driving range data for each model. We collect certified driving range in kilometers under WLTP for each ZEV model in our vehicle database. This specification measures the maximum distance that a BEV can travel on a full charge without recharging, or an FCEV can travel on a single tank of hydrogen without refueling.

Similar to energy consumption, driving range of BEV models in the database is measured using different test cycles. We follow the same method to standardize the range values of different test cycles to WLTP-equivalent driving range using conversion factors. We apply a discount factor of 1.15 to convert the NEDC or CLTC range to its equivalent value under the WLTP test cycle. Similarly, a multiplier of 1.2 is used to convert the U.S. label values to their equivalent values under the WLTP test cycle (Yoney, 2022).

This data is then weighted based on the total sales of each model in the six major markets in 2022, and it results in a weighted average that reflects the typical driving range under laboratory testing. The average driving range of each manufacturer is then converted to a 100-point score following Equation (1). The manufacturer with the longest sales-weighted average range receives a score of 100 and the manufacturer with the shortest receives a score of zero. Other manufacturers are scored based on their relative driving range compared with the best and worst performers and receive a score between zero and 100.

There is some overlap between the energy consumption metric and the driving range metric, because the efficiency of a vehicle is a key determinant of its driving range. However, it is important to consider both metrics in this assessment, because both aspects are important to the consumer experience: Efficiency is a major factor in recharging costs and driving range affects the convenience of driving BEVs.

RESULTS

The average driving range varies greatly among the 20 manufacturers, from 196 km on the low end to 503 km on the high end. The top 10 manufacturers on this metric exhibit relatively similar driving ranges, all exceeding 400 km, and the remaining manufacturers are distributed across the range of 196 km to 355 km. Figure 6 shows the final score for each manufacturer and the average driving range of their ZEV models.

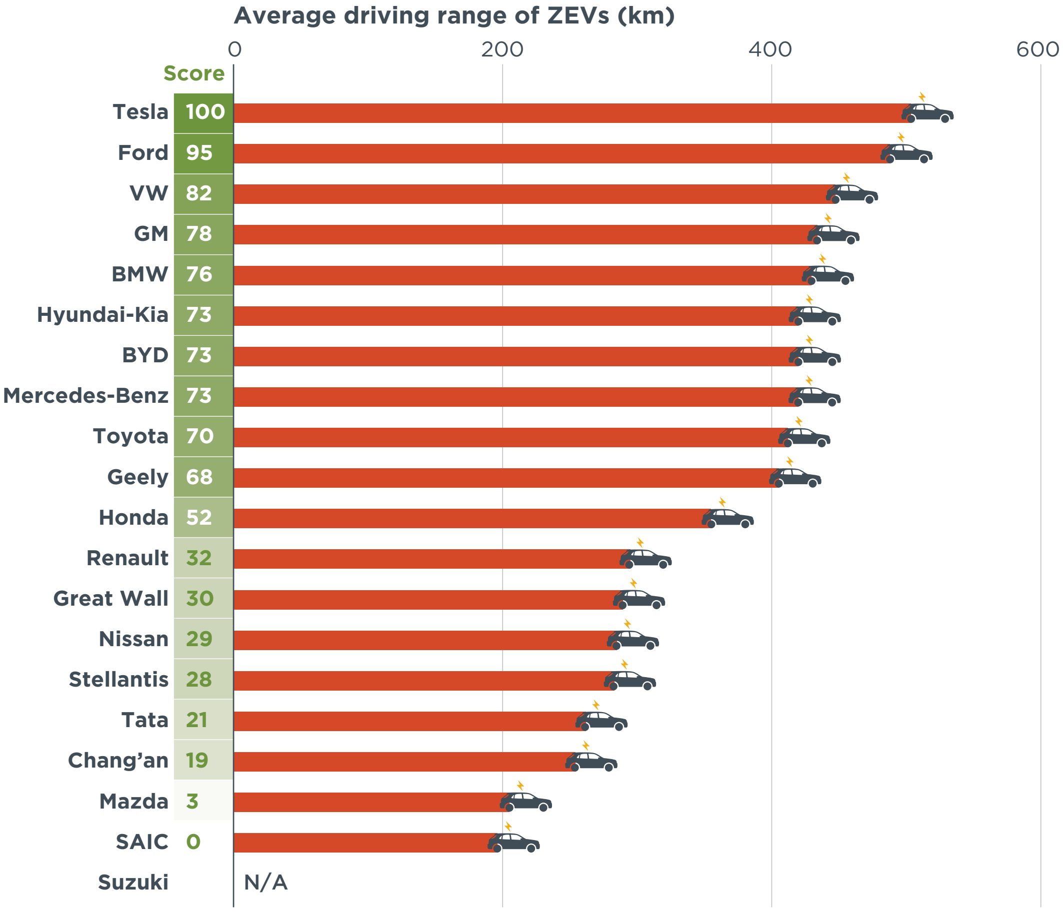

Figure 6. Fleet-average driving range of ZEVs and metric score by manufacturer.

Tesla leads with an average driving range of 503 km. Second place Ford performs well with an average driving range of 488 km, which is largely attributable to its strong-selling BEV model Mustang Mach-E, which has an average of 505 km of range. The average ZEV driving distances of VW, GM, BMW, Hyundai-Kia, BYD, Mercedes-Benz, Toyota, and Geely range from 400 km to 450 km. These manufacturers have strong-selling models that offer substantial average driving ranges, such as the IONIQ series (487 km) from Hyundai-Kia, the ID.5 (503 km) from VW, and the EQA (426 km) from Mercedes-Benz. Honda, Renault, Great Wall, Nissan, and Stellantis have lower average driving ranges between 283 km and 355 km.

Tata, Chang'an, Mazda, and SAIC are behind on this metric. SAIC has the lowest average driving range of 196 km. These manufacturers sell large volumes of less-expensive BEVs that are aimed at urban dwellers. For instance, the Hongguang Mini, one of SAIC's most successful models, is most popular among office workers in urban areas (36kr, 2020) and offers a driving range of 120 km, which is designed to meet daily commuting needs. Suzuki does not have a score for this metric because it did not sell any ZEVs in 2022.

While average driving range is an important metric, it has limitations. The increased costs and larger battery packs might not be attractive to consumers beyond a certain point. Moreover, some companies, such as SAIC, might strategically choose to focus on BEVs with shorter ranges to provide less-expensive options for daily commuters. Because this evaluation is forward-looking, manufacturers with low average driving ranges are given low scores even though some might succeed in BEV sales by targeting shorter-range vehicles and serving a narrow market segment. However, in order to drive greater market growth and reach a wider range of consumers in the future, longer-range vehicles are necessary to address all consumer needs and facilitate a full transition to ZEVs.

4.4 Renewable energy in manufacturing

Renewable energy in manufacturing reflects efforts to decarbonize manufacturing operations, including using renewable energy in vehicle and battery production. With the transition from ICEVs to ZEVs, the relative importance of GHG emissions from manufacturing activities will increase and become a necessary area of focus in decarbonizing the industry. An ICCT study estimating the life-cycle GHG emissions from average mid-size passenger cars registered in Europe, the United States, China, and India in 2030 found that the share of emissions from vehicle manufacturing would range from 16%–36%, and the share from battery manufacturing would range from 10%–15%, both depending on the region (Bieker, 2021). The renewable energy in manufacturing metric is important for evaluating the progress of manufacturers in transitioning to 100% renewable energy for manufacturing vehicles and batteries. Decarbonization efforts in the supply chain are also important as long as auto manufacturers outsource battery production.

Note that there are other sources of upstream emissions associated with the manufacturing of motor vehicles. Material sourcing, including extraction and processing, is one such contributor. While the estimated 2030 production emissions shares cited above include material sourcing, this analysis does not include material sourcing due to the lack of comprehensive information on manufacturers' efforts to source low-emission materials. Fossil fuels such as natural gas are sometimes also used as direct energy inputs (other than electricity) in the vehicle production process, but we do not account for fossil fuel use in this report because we found no evidence of any of the manufacturers phasing out fossil fuel inputs at either vehicle or battery production sites. As manufacturers progress in decarbonizing upstream emissions and more data becomes available for evaluation, we will consider incorporating material sourcing and fossil fuel use in future iterations of this rating.

METHODOLOGY

The evaluation of manufacturing decarbonization is based on (a) renewable electricity in vehicle assembly and (b) renewable electricity in battery production. Every manufacturer receives a score for each of these two factors, and averaging the scores of the two factors provides the final score for this metric. The two factors have the same weight because estimates using the GREET model show that vehicle and battery manufacturing contribute similar levels of production emissions (Argonne National Laboratory, 2022).

a. Renewable electricity use in vehicle manufacturing and assembly

A manufacturer receives 1 point if it uses 100% renewable electricity in all plants within a region and zero points otherwise. The final point total is the sales-weighted average of regional points across the six major markets.

We only give credit to manufacturers that exhibit a commitment to 100% renewable energy because manufacturers can achieve 100% renewable energy by purchasing renewable energy certificates in most regions. In addition, in regions like Europe, where renewable electricity was already between 30% and 40% of the local power grid in 2021 (Enerdata, 2021; van Halm, 2023), it requires less effort for manufacturers to achieve the 100% renewable energy target.

There are manufacturers that have built or are building on-site renewable energy generation capacity. Manufacturers headquartered in China are among those making these investments. However, the power generation capacity of these renewable energy projects is minimal compared with total manufacturing electricity use, and these do not qualify for points based on the established criteria.

b. Renewable electricity use in battery production

A manufacturer receives 1 point if it uses 100% renewable electricity at its battery plants, if it has any battery plants, and if it requires battery suppliers to use 100% renewable electricity. Zero points are awarded otherwise.

Although some manufacturers are ramping up their own battery production capacities, almost all manufacturers in this report rely on battery suppliers for ZEV production. Therefore, evaluating decarbonization efforts consists of not only the renewable electricity use at manufacturers' own battery plants but also those of the battery providers, which the manufacturers can influence through procurement requirements.

After averaging the scores from (a) and (b), we convert the combined raw point value to a 100-point scale using Equation (1). The manufacturer with the best performance receives a score of 100 and the worst receives a score of zero. Per Equation (1), other manufacturers are scored based on their performance relative to the best and worst performers.

RESULTS

Manufacturers have varying levels of renewable electricity use across their global production sites, but three of the manufacturers headquartered in Europe, BMW, VW, and Mercedes-Benz, are far ahead of the others. Table 2 presents information on the global share of renewable electricity use at vehicle and battery production plants and indicates whether there is a renewable electricity requirement for battery suppliers. Cells highlighted in light yellow represent efforts that received credit based on our scoring methodology explained above.

Table 2. Use of renewable electricity for vehicle and battery production and metric score by manufacturer

OEM	Renewable electricity use at vehicle and battery production plants[a]		Renewable electricity use by battery suppliers		Score
	Share of electricity that is renewable	**Scope of production plants**	**Source batteries from suppliers?**	**Require suppliers to use renewable electricity?**	
BMW	100%	Global plants	Yes	Yes	100
VW	54%	Global plants	Yes	Yes	75
	100%	44 plants in the European Union			
	100%	18 non-EU plants			
Mercedes-Benz	100%	Global plants	Yes	No	50
Ford	43%	Global plants	Yes	No	14
	100%	All plants in Europe			
Hyundai-Kia	100%	All plants in the European Union	Yes	No	11
Geely	6% (Geely)	Global plants	Yes	No	9
	100% (Volvo Cars)	All plants in the European Union			
Toyota	13%	Global plants	Yes	No	6
	100%	All plants in the European Union			
	100%	Several plants in South America			
Tata	19% (Tata)	Global plants	Yes	No	6
	100% (JLR)	All plants in Europe			
GM	30%	Global plants	Yes	No	0
Stellantis	27%	Global plants	Yes	No	0
	100%	Several plants in the European Union and South America	Yes	No	
Honda	12%	Global plants	Yes	No	0
Suzuki	44 MWh	Plants in India	Yes	No	0
Nissan	7%	Global plants	Yes	No	0
Chang'an	37,672 MWh	Plants in China	Yes	No	0
BYD	44,000 MWh	Plants in China	No	No	0
Renault	100%	Plants in Brazil, Morocco, Romania, and Spain	Yes	No	0
Tesla	30%	Global plants	Yes	No	0
SAIC	230 MWh	Plants in China	Yes	No	0
Great Wall	71,000 MWh	Plants in China	Yes	No	0
Mazda	1.1 MWh	Plants in Japan	Yes	No	0

[a] Cells in yellow indicate 100% renewable electricity use of all of the manufacturer's plants in one of the six major markets or all plants globally.

BMW receives the highest score for this metric. In all BMW production sites, the electricity used is from 100% renewable sources. In addition, BMW has contractual agreements that require its battery manufacturers to use only renewable electricity in production. VW and Mercedes-Benz trailed closely. For VW, approximately 99.6% of the electricity across its European Union sites was renewable electricity in 2022; VW gets credit, then, for using nearly 100% renewable electricity in the European Union, its largest market. Further, VW previously required its tier 1 battery cell suppliers to use 100% renewable electricity, but decarbonization requirements were changed in 2022 to allow suppliers to adopt other pathways, including further optimization of processes. We give VW credit, as the use of renewable electricity is a common pathway to meet the requirement. Mercedes-Benz also achieved 100% renewable sources for all the electricity used in its global plants.

Ford, Hyundai-Kia, Geely, Toyota, and Tata received partial credit as they have transitioned to 100% renewable electricity at vehicle production sites in certain regions. Ford's production plants in the European Union and the United Kingdom, which represent nearly 30% of its LDV sales, are sourced from 100% renewable electricity. Volvo Cars, part of Geely Group, reports that approximately 93% of its global electricity consumption comes from renewable sources, and that its EU plants consume 100% renewable electricity. The other manufacturers are given credit for using 100% renewable electricity in their vehicle production sites in Europe or the European Union, which make up between 12% and 22% of their sales.

The remaining manufacturers did not meet the criteria of using 100% renewable electricity manufacturing and assembling in any region. Manufacturers based in China have shown some progress in using renewable energy through additional on-site electricity generation. For example, in 2022, Great Wall, BYD, and Chang'an reported generating approximately 71 GWh, 44 GWh, and 37 GWh of electricity, respectively, from solar power. However, these amounts are a small fraction of the total electricity use of these manufacturers and they each receive a score of zero.

Efforts to decarbonize the supply chain, including the requirement for battery suppliers to use renewable energy, were lacking. Besides BMW and VW, Mercedes-Benz and Volvo Cars are the only other manufacturers that have contracts with some battery cell partners that require them to only produce batteries with renewable electricity. Nevertheless, Mercedes-Benz and Volvo Cars did not receive credit for this because the requirement is not applied to all battery providers.

Although no manufacturer has completely phased out all fossil fuel inputs other than electricity for vehicle and battery production, BMW and VW are expanding the use of other renewable energy sources across vehicle and battery production plants, and they aim to increase on-site renewable energy generated at an industrial scale. GM is also expanding renewable energy projects, including on-site solar facilities across multiple facilities in the United States and Brazil. Mercedes-Benz is increasing the use of geothermal energy and biomethane for production processes at its plants in Germany. For heating, Renault noted the use of biomass heaters in its plants in Morocco and Brazil, and Stellantis uses solar thermal panels at its plant in Italy. In the future, as more significant actions are taken to phase out all fossil fuel inputs, new benchmarks will be set for using renewable energy for manufacturing.

4.5 Battery recycling and repurposing

Increased ZEV production means increasing demand for raw materials used to produce EV batteries and thereby increasing the share of emissions from battery material sourcing, extraction, and processing. Battery recycling and repurposing can reduce the demand for raw materials through recovering critical materials to produce new batteries or reusing batteries for second-life applications. Recycling and repurposing are also important given the rapid growth in the manufacture of batteries for EVs; manufacturers will need to navigate potential future scarcity of essential raw materials and related fluctuations in raw material prices to secure the batteries needed for ZEV production.

A recent study by the ICCT (Tankou et al., 2023) estimated that recycling EV batteries from both light- and heavy-duty vehicles, partially after their prolonged use in second-life applications, could reduce the total demand for new lithium, cobalt, nickel, and manganese mining by 3% in 2030, 11% in 2040, and 28% in 2050. For LDVs specifically, assuming the battery is expected to last through the entire vehicle lifetime, reusing half of the end-of-life EV batteries could increase the cumulative capacity for second-life applications (e.g., electricity storage) from 1 GWh in 2022 to approximately 50 GWh in 2030, and then to 6,500 GWh in 2050 (Tankou et.al, 2023). Further, it was estimated that battery recycling could reduce the GHG emissions from lithium-ion battery production up to 25% and could further reach 50% of reduction for a full recycling of Lithium-Nickel-Manganese-Cobalt-Oxide (NMC) cathode materials (Argonne National Laboratory, 2020).[4] Therefore, battery recycling and repurposing are important actions that manufacturers should take to maximize GHG reductions in support of a full ZEV transition.

METHODOLOGY

This metric evaluates manufacturer efforts in developing battery recycling systems and carrying out battery repurposing initiatives. Both approaches help to reduce the carbon footprint of battery production and material sourcing. A well-established battery recycling system allows for the recovery and reuse of valuable materials such as lithium, cobalt, and nickel from retired batteries to produce new batteries and reduces the need for new raw materials and the emissions from their extraction and processing. Battery repurposing involves reusing batteries that have reached the end of their useful first life in other applications, such as backup power or electricity storage for factories, and it reduces the need for new battery production and the associated emissions. Electricity consumption and emissions from the grid can also be decreased by integrating repurposed batteries as energy storage in renewable energy installments like solar panels at vehicle manufacturing facilities.

A manufacturer gets 1 point for having either battery recycling or repurposing projects in a given region, or a zero when there are no ongoing battery recycling projects in the region. The final score is the sales-weighted average of regional points across the six major markets. Then, we convert the final scores to a 100-point scale using Equation (1). The manufacturer with the best performance receives a score of 100 and the worst receives a score of zero. Other manufacturers are scored based on their relative metric points compared with the best and worst performers.

We do not differentiate recycling projects based on the recycling capacity or repurposing scale. There are increasing efforts in battery recycling and repurposing in recent years, but both are at the early stage, and the majority of actions and projects on battery recycling and repurposing are pilot projects or small-scale initiatives. As of 2022, the volume of end-of-life batteries from EVs that can be recycled was still low,

4 The total estimated GHG emissions reductions from battery recycling strongly depends on the electrode materials and the applied recycling processes.

with most recycling related to production scrap. Therefore, there is a lack of sufficient information to compare recycling capacities and the emissions-reduction impact of those efforts. Future analysis could quantitatively measure and differentiate these efforts as more EV batteries become available for recycling and repurposing and as more data about projects and their capacity become available.

RESULTS

Most manufacturers have some sort of battery recycling and repurposing project. Overall, manufacturers are still in the early phases of these projects, and they are in the form of pilot studies, memorandums of understanding, and strategic partnerships. Table 3 summarizes auto manufacturers' battery recycling and repurposing efforts across the six markets as of the end of 2022. The ♲ symbol indicates a manufacturer has a battery recycling system project and a 🛢 symbol indicates a manufacturer has a battery repurposing project. The table also shows the market share of LDVs in the regions where the manufacturers have deployed battery recycling and repurposing projects and the final score after rescaling. A cell with market share but without any symbol means the manufacturer does not have a battery recycling or repurposing project in that market where they sell vehicles.

Table 3. Manufacturers' battery recycling and repurposing-related actions by region as of 2022, with the region's percentage of total vehicle sales for each automaker (%)

OEM	China	U.S.	Europe	Japan	India	Korea	Score
Geely	♲ 🛢 75%	♲ 🛢 6%	♲ 🛢 16%	♲ 🛢 1%	♲ 🛢 <1%	♲ 🛢 1%	**100**
Hyundai-Kia	♲ 🛢 6%	♲ 🛢 30%	♲ 🛢 22%	♲ 🛢 <1%	♲ 🛢 17%	♲ 🛢 25%	**100**
Tesla	♲ 37%	♲ 44%	♲ 19%				**100**
BYD	♲ 🛢 100%			<1%	<1%		**100**
Great Wall	♲ 100%		<1%				**100**
GM	🛢 25%	♲ 🛢 74%	<1%	<1%		1%	**99**
Stellantis	♲ 🛢 2%	♲ 🛢 37%	♲ 🛢 60%	<1%	<1%	<1%	**98**
BMW	♲ 33%	♲ 🛢 18%	♲ 🛢 41%	3%	<1%	5%	**92**
Ford	9%	♲ 64%	♲ 28%	<1%		<1%	**91**
Renault	<1%		♲ 🛢 90%	<1%	6%	4%	**90**
SAIC	♲ 🛢 90%		7%		3%		**90**
Tata	4%	7%	♲ 🛢 12%	<1%	♲ 75%	1%	**87**
Toyota	26%	♲ 🛢 31%	13%	♲ 🛢 28%	2%	<1%	**59**
VW	38%	10%	♲ 49%	1%	2%	<1%	**49**
Mercedes-Benz	31%	18%	♲ 🛢 43%	3%	<1%	4%	**43**
Honda	44%	♲ 32%	2%	19%	3%	<1%	**32**
Nissan	36%	32%	🛢 11%	🛢 20%	1%		**31**
Chang'an	100%						**0**
Mazda	11%	44%	21%	24%			**0**
Suzuki			6%	26%	68%		**0**

♲ = recycling 🛢 = repurposing

Geely, Hyundai-Kia, Tesla, BYD, and Great Wall are leading on this metric, mainly through partnerships and investments in their dominant markets. Geely established a company, Jiangxi Yiyuan New Energy Technology Co., to work in the battery recycling industry in China and Volvo Cars, part of Geely, operates a global battery disposal and recycling program and has partnered with BatteryLoop to reuse EV batteries in Europe and with Redwood Materials to develop closed-loop EV battery system in California. The Hyundai Motor Group is in partnership with Hyundai GLOVIS, which will reuse used EV batteries for its energy storage system and procure waste batteries from junkyards and dealers globally for remanufacturing. The Hyundai Motor Group and its brand Kia Europe are also collaborating with partners in the United States and Europe, respectively, on energy storage systems from used EV batteries. Tesla established an internal ecosystem to re-manufacture batteries coming from the field to its service centers across its markets and is building battery recycling capacity through in-house cell recycling facilities, closed-loop cathode production, and partnerships with recycling companies in its biggest markets, the United States and China. BYD partnered with a major battery recycling company and currently operates about 40 battery recycling outlets across China; it also formed a partnership with a Japanese trading company to repurpose used batteries for energy storage systems for renewable energy facilities. Great Wall's subsidiary, Honeycomb Energy, announced its entry into the field of battery recycling in November 2022; it plans to advance closed-loop battery recycling in China.

Many manufacturers have also shown progress with battery recycling and repurposing projects in the market where they are headquartered and where there is a high share of their sales. For example, GM and Stellantis are in partnership with recycling companies to establish closed-loop battery recycling and repurposing systems for stationary storage across the United States, where GM is headquartered, Europe, where Stellantis is headquartered, and China which is a big market for both GM and Stellantis.

The remaining manufacturers have commenced projects in their home markets and announced plans for expansion in other major markets. For example, Mercedes-Benz Group is establishing a pilot battery recycling plant in Kuppenheim, Germany. It is also planning to set up a closed-loop battery recycling system in China and United States with partners in the future; this would be reflected in future ratings, if there is concrete progress. VW opened its first in-house recycling facility at the Salzgitter plant and Ford is partnering with U.S. recycling company Redwood Materials to recycle its batteries.

Regarding manufacturers headquartered in Japan, Toyota and Honda recently entered into strategic partnerships with Redwood Materials (Toyota) and Battery Resourcers (Honda) to recycle EV batteries and develop second-life opportunities to repurpose EV batteries in the United States. Nissan has been exploring opportunities and mechanisms for battery repurposing such as battery storage systems. Both Suzuki and Mazda have established a battery collection and recycling mechanism for batteries employed in their hybrid vehicles in Japan and overseas (India and Europe for Suzuki). However, we do not give credit for these efforts because there is no clear indication that these technologies are used for recycling or reusing batteries from BEVs. No company-level battery recycling effort was identified for Chang'an.

5 STRATEGIC VISION

5 STRATEGIC VISION

5.1 ZEV target

The ZEV target metric evaluates the ambition of a manufacturer in transitioning to a 100% ZEV fleet to be on pace with the Paris Agreement timeline. An ambitious target can demonstrate a manufacturer's determination to decarbonize its vehicle fleet. In contrast, a manufacturer without a target, or with a weak ICEV phase-out target, is considered less likely to invest in the ZEV transition in the near term. This metric was developed to carefully review and compare manufacturers' announcements regarding a full ZEV transition.

METHODOLOGY

The primary sources of ZEV target information are manufacturers' sustainability reports, announcements, press releases, and news articles available as of the end of 2022. A number of manufacturers have announced targets pertaining to all or some of their fleets over the next decade or two. These targets vary in several ways, including in terms of timeframe (2025, 2030, or 2035), geographical coverage (global or regional), segments covered (passenger cars only or all LDVs), and technology type (ZEV or ZEV + PHEV).

We establish benchmarks to compare the level of ambition. According to ICCT estimates, the major vehicle markets should reach 77% ZEV market share by 2030 and 97% by 2035 in order to align with the Paris Agreement (Sen & Miller, 2022).[5] Thus, for this analysis, we set the benchmark for ZEV targets in the six major markets at 77% by 2030 and 97% by 2035.

We derive the ZEV target score by calculating the ratio of the manufacturer's ZEV sales target to its corresponding benchmark. A ZEV target for 2030 is compared with the 2030 benchmark and a ZEV target for 2035 is compared with the 2035 benchmark. The two manufacturers that have already committed to 100% EV sales, Tesla and BYD, get a maximum score of 100, but BYD's score is adjusted downward as it will still produce PHEVs. Further, although short-term targets are better than long-term targets because they show serious commitment now rather than later, anything prior to the benchmark is not rewarded with a higher ZEV target score. In cases where manufacturers only have a target for 2025, we compare the target against the 2030 benchmark and assume the ZEV market share will not grow beyond 2025 in the absence of a longer-term target. The resulting value can be larger than 100% if the manufacturer has a more ambitious target than the benchmark.

Some manufacturers have multiple ZEV targets with different scopes, and these are targets apply to certain regions, subsidiary brands, and vehicle types (i.e., passenger cars only or all LDVs). For each announced target, we calculate the ZEV target score and determine the affected vehicle sales based on the target scope. Some automakers' announcements of ZEV targets are worded generally to apply to sales in "the leading markets." We assume that "the leading markets" include all six regions investigated in this analysis unless a different scope is clarified in the automaker's statement. Then, we calculate the sales-weighted average score of the different targets, if any, for each manufacturer. If there are overlaps between a manufacturer's multiple ZEV targets in

5 Major markets in the analysis include China and the members of the ZEV Transition Council (Canada, Denmark, the European Commission, France, Germany, India, Italy, Japan, Mexico, Netherlands, Norway, Spain, South Korea, Sweden United Kingdom, and the United States).

year and/or region, we select the most ambitious targets that give the highest score to manufacturers after accounting for the fraction of regional sales based on our methodology. For example, Honda has announced a ZEV target of 40% by 2030 and a ZEV target of 80% by 2035 for the United States, China, and Japan. We selected the latter to be the ZEV target of Honda for this analysis, as it gives Honda a higher score.

Furthermore, we consider BEVs, FCEVs, and the ZEV-equivalent portion of PHEVs when calculating the ZEV target. Although most manufacturers set their targets for only ZEVs, the Chinese manufacturers have only announced EV targets that include both ZEVs and PHEVs, and the split is not specified. To extract the potential ZEV market share that these manufacturers can achieve with their announced targets, we discount their ZEV targets using the ratio between ZEV-equivalent share and the actual EV share of 2022, which is calculated and summarized in Section 3.1. This approach considers both the PHEV share of total EV sales in 2022 and the real-world electric drive share of PHEVs sold by the manufacturer. For instance, for Great Wall, which sets an EV target of 80% by 2025 and has a ratio of 0.95 between its ZEV-equivalent sales and total EV sales in 2022, we adjusted the EV target by using 80% * 0.95 = 76% to obtain the ZEV-equivalent target.

We do not consider a target that includes conventional (non-plug-in) hybrid vehicles as a ZEV target, since conventional hybrid vehicles cannot be recharged with grid or renewable electricity. Furthermore, an electrification target that includes hybrids could be dominated by hybrids, thereby stifling the growth of ZEVs.

Lastly, we convert the final value of the adjusted ZEV target to a 100-point scale using Equation (1). The manufacturer with the most ambitious ZEV target receives a score of 100 and the least ambitious receives a score of zero. Per Equation (1), other manufacturers' ZEV targets are scored relative to the best and worst performers and receive a score between zero and 100.

RESULTS

There are nine automakers that have 100% ZEV targets for at least one brand in leading markets. Besides Tesla, which already produces and sells only ZEVs, Tata-Jaguar has a 100% ZEV target for 2025, and Geely-Volvo, Toyota-Lexus[6], and VW-Bentley all have a 100% ZEV target for 2030. BMW-Mini GM, Ford, and Mercedes-Benz have a 100% ZEV target for 2035. Table 4 summarizes the EV sales target for each auto manufacturer at the global and regional levels, including the targeted market share, target year, applicable vehicle technology, vehicle segment, and the final score for the ZEV target metric after rescaling.

6 Toyota-Lexus's 100% ZEV target for 2030 is not shown in Table 4. Toyota's score is based on Toyota's corporate-level target because it results in a better score for Toyota.

Table 4. Announced EV sales targets and metric score, by manufacturer

OEM	Brand	Electric vehicle (EV) sales target					Score
		Region	EV sales	Segment[a]	Year[b]	Type	
Tesla	**All**	Global	100%	LDV	N/A	ZEV	**100**
Renault	**Renault**	Europe	100%	LDV	2030	ZEV	**100**
	Dacia	Europe	100%	LDV	2035	ZEV	
	Others	—	—	—	—	—	
GM	**All**	Leading markets	100%	LDV	2035	ZEV	**96**
Ford	**All**	Leading markets	100%	LDV	2035	ZEV	**96**
Mercedes-Benz	**All**	Leading markets	100%	LDV	2035	ZEV	**96**
Great Wall	**All**	Global	80%	LDV	2025	ZEV, PHEV	**92**
VW	**VW**	Europe	70%	PC	2030	ZEV	**92**
		United States	50%	LDV	2030	ZEV	
		China	50%	LDV	2030	ZEV	
	Audi	Global (excl. China)	100%	LDV	2033	ZEV	
	Škoda	Europe	70%	LDV	2030	ZEV	
	Bentley	Global	100%	LDV	2030	ZEV	
	Porsche	Global	80%	LDV	2030	ZEV	
	Others	—	—	—	—	—	
Stellantis	**All**	Europe	100%	PC	2030	ZEV	**81**
		United States	50%	LDV	2030	ZEV	
Honda	**All**	Leading markets	80%	LDV	2035	ZEV	**73**
BMW	**BMW**	Global	50%	LDV	2030	ZEV	**72**
	Mini	Global	100%	LDV	2035	ZEV	
Geely	**Volvo Cars**	Global	100%	LDV	2030	ZEV	**71**
	Others	Global	40%	LDV	2025	ZEV, PHEV	
BYD	**All**	Global	100%	LDV	N/A	ZEV, PHEV	**70**
Chang'an	**All**	Global	60%	LDV	2030	ZEV, PHEV	**68**
Nissan	**All**	Global	50%	LDV	2030	ZEV, PHEV	**60**
Tata	**Tata**	Global	30%	LDV	2030	ZEV	**52**
	Jaguar	Leading markets	100%	LDV	2025	ZEV	
	Land Rover	Leading markets	100%	LDV	2035	ZEV	
Hyundai-Kia	**Hyundai, Genesis**	Global	36%	LDV	2030	ZEV	**39**
	Kia	Global	30%	LDV	2030	ZEV	
Toyota	**All**	Global	32%	LDV	2030	ZEV	**39**
SAIC	**All**	Global	32%	LDV	2025	ZEV, PHEV	**37**
Mazda	**All**	Global	25%	LDV	2030	ZEV	**30**
Suzuki	**All**	—	—	—	—	—	**0**

[a] LDV = Light-duty vehicle; PC = passenger car
[b] ZEV = zero-emission vehicle (including battery electric vehicle and fuel-cell electric vehicle); PHEV = plug-in hybrid electric vehicle

As Tesla only produces and sells ZEVs, it received the highest score for this metric. BYD began to produce and sell only EVs in March 2022, but its final score is discounted because BYD counts PHEVs toward its target, and those accounted for 50% of the EVs it sold in 2022. Renault aims to fully transition to 100% ZEVs for the Renault brand by 2030 and by 2035 for the Dacia brand, both in Europe, its largest market which was home to 90% of its LDV sales in 2022. GM, Ford, and Mercedes-Benz scored well with a 100% ZEV sales target for LDVs in leading markets by 2035; this reflects their commitment as signatories of the COP26 declaration ("COP26 declaration," 2021).

VW and Stellantis are more ambitious in their commitments in Europe than elsewhere and focus on passenger cars, rather than on the broader LDV segment. For example, the VW brand under the VW Group has a 2030 ZEV target of 70% for passenger cars in Europe, but only has a 50% ZEV target for LDVs by 2030 for the United States.

Aside from BYD, Chinese manufacturers received lower scores relative to other manufacturers because they all set short-term targets and count PHEVs toward their EV sales targets. Under the Geely Group, Geely has set a global target of 40% by 2025, including PHEVs, and Volvo Cars set a more ambitious global target of 100% ZEVs by 2030. For Hyundai-Kia, Hyundai aims to have 36% of its global sales (including Genesis) be ZEVs by 2030 and Kia aims to have ZEVs be 30% global sales by 2030. India-headquartered Tata also has multiple targets across its brands. The Tata brand has a worldwide target of at least 30% ZEV sales by 2030, and the Jaguar and Land Rover brands aim to achieve 100% ZEVs by 2025 and 2035, respectively, in the leading markets.

Over the past year, manufacturers headquartered in Japan have shown more commitment on this metric, but still lag manufacturers headquartered in other major markets. Nissan and Honda announced global or leading market ZEV targets of 50% by 2030 and 80% by 2035, respectively, and both are more ambitious than Toyota's (approximately 32% ZEVs by 2030) and Mazda's (25% ZEVs by 2030). Toyota formerly included hybrids in its global plan but updated its target in 2021 and aims to sell 3.5 million BEVs globally by 2030. To infer Toyota's 2030 target from this goal, we estimated the company's global LDV sales in 2030 based on its 2022 global LDV production and an annual growth rate of 2.2% (i.e., the compounded annual growth rate of Toyota's global production from 2011–2022). Suzuki receives a score of zero as it had not announced any ZEV target as of the end of 2022.

5.2 ZEV investment

ZEV investment is a measure of a manufacturer's financial commitment to the transition to zero-emission technology. Historically, manufacturers have invested in the next generation of ICEVs to improve vehicle performance and efficiency and to reduce emissions. Some legacy companies have announced plans to stop investing in new ICEVs and stop making significant improvements to existing ICEVs, and some companies have committed to making large investments in ZEVs. While investment commitments do not by themselves guarantee the ZEV transition, without such commitments, the likelihood of the transition seems low, or at least the transition would take much longer. Such expenditure is an investment in risk reduction. The level of investment in zero-emission technologies illustrates the progress in shifting the business to ZEV development.

METHODOLOGY

This metric evaluates a manufacturer's investment in the ZEV transition. We consider R&D; capital expenditure on things such as the development of ZEV production sites to increase manufacturing capacity and ZEV supporting infrastructure like construction of battery plants and charging stations, and establishment of the broader charging network; and financial outlays for other things like establishing subsidiaries, joint ventures, and partnerships.

Our primary source of investment data was the Atlas EV Hub, an online database developed by Atlas Public Policy (2022). The database documents EV investments announced by major manufacturers worldwide from 2016 to 2022. We also collected additional investment information from sustainability reports and official press releases to verify Atlas EV Hub data and updated the investment data when discrepancies were found. We collected information on both the monetary amount and the investment period for ZEV investments that were announced from 2016 to 2022.

Some manufacturers have announced EV investment in combination with other advanced vehicle technologies such as smart transportation or autonomous driving technology. In these cases, we derived the EV investment amount either from the EV-specific portion that the manufacturers provided to us or by splitting the investment amount equally between the different types of technologies named.

The total investment is evaluated in terms of 2022 U.S. dollars per vehicle. We assumed an investment recovery period of 10 years, given the transitional nature of the current ZEV market, which requires a longer recovery period for investments than would be expected in a more mature market. Moreover, given that investments are made over varying time frames, we used cumulative ZEV investment as our absolute financial measure. We adjusted for the time value of money by using a discount rate of 3.2%, based on the average of Organisation for Economic Co-operation and Development's annual inflation rate from 2016 to 2022 (Organisation for Economic Co-operation and Development, 2022). However, we did not attempt to adjust sales over the recovery period and used 10 years of 2022 sales as the recovery basis.

While this methodology reflects investments normalized by a manufacturer's size in terms of sales, the metric is not a precise measure for any manufacturer for several reasons. For one, the lifetime of investments spans several sales years, and the recovery period varies not only across manufacturers, but between the separate investments of any given manufacturer. Sales also vary both geographically and over time, so the number of vehicles over which any recovery might be generated is also uncertain. While the ZEV investment metric therefore contains some uncertainty, it is a self-consistent and reasonable measure of the relative level of investment across manufacturers.

To adjust for the time value of money, we first distribute each announced investment evenly across the announced period to generate a stream of annualized investment. In the absence of stated duration, we assume an investment period of 10 years. The investment amount of each year is adjusted to 2022 U.S. dollars. Then we sum up the present values of these annualized investments to generate the investment amount in 2022 dollars. Furthermore, investment announcements typically do not specify the investment split between different power trains, for example BEVs and PHEVs. In order to reflect the ZEV investment amount manufacturers are committed to, similar to the ZEV target metric, we consider BEVs, FCEVs, and the ZEV-equivalent portion of PHEVs when calculating the ZEV investment. We adjust their investments using the ratio between ZEV-equivalent share and the actual EV share of 2022, which is calculated and summarized in Section 3.1.

We then divide the cumulative investment amount in 2022 U.S. dollars by the product of the total LDV sales in six major markets in 2022 and the investment return period of 10 years to derive the investment per vehicle. Last, we convert the values for total investment per vehicle to a 100-point scale using Equation (1). The manufacturer with the highest ZEV investment per vehicle receives a score of 100 and the lowest receives a score of zero. Other manufacturers are scored based on their relative metric points compared with the best and worst performers and receive a score between zero and 100.

RESULTS

Automakers have significant differences in their announced financial commitments, in terms of per-vehicle investment values and cumulative absolute investment values. Figure 7 shows the investment levels, with manufacturers arranged left to right from highest to lowest in terms of investment per vehicle sold. The bubble size reflects the size of the total investments announced by each manufacturer in 2022 U.S dollars. Table B4 in Appendix B further details the cumulative investments in EV plans announced by each manufacturer from 2016 to 2022, the investment values in 2022 dollars, the adjustment factor from EV to ZEV, and the resulting investment per vehicle.

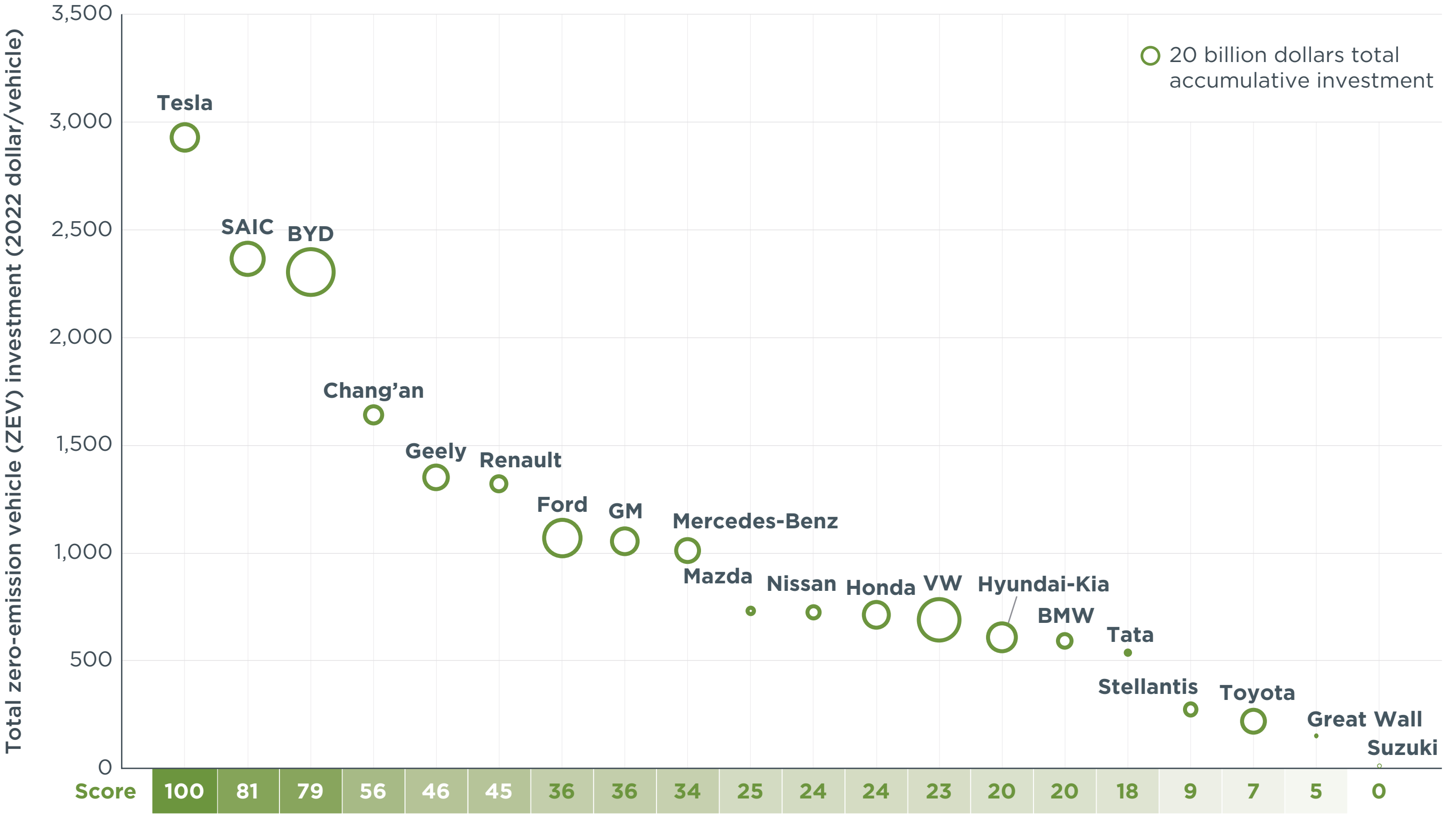

Figure 7. ZEV investment by manufacturer, as gleaned from public sources including Atlas EV Hub, and metric scores.

Tesla is leading in terms of investment per vehicle sold ($2,929) and SAIC ($2,364) and BYD ($2,305) trail closely, as both ramped up EV production and invested in an EV future. Although VW has the largest cumulative investment in 2022 U.S. dollars among all manufacturers, as the second largest LDV manufacturer in the world, VW's score for this metric is behind a number of others after taking the size of the company into account.

Renault is doing well in investment compared with other Europe-headquartered automakers, and two manufacturers headquartered in China, Chang'an and Geely, have ZEV investment in the range of $1,300 to $1,650 per vehicle. Ford and GM have a per-vehicle investment of slightly over $1,000, and they are closely trailed by Mercedes-Benz.

Mazda, Nissan, and Honda scored better than other manufacturers headquartered in Japan with over $700 invested per vehicle sold. Toward the end of 2022, Mazda revealed an approximately $11 billion plan to boost EV sales through 2030. The top four largest automakers are all behind on per-vehicle investment, but VW and Hyundai-Kia had higher investments per vehicle (between $600 and $700) than Stellantis and Toyota, which invested between $200 and $300 per vehicle sold. BMW and Tata each had investment per vehicle between $500 and $600.

Suzuki received the lowest score because of its lack of commitment during the investment period analyzed. While the company announced an investment plan of $35 billion in BEV production through 2030 in January 2023, it is not taken into account as it is beyond the time scope of the analysis (Suzuki, 2023). This will be reflected in next year's rating.

Some manufacturers announced investments to support the development of charging infrastructure as part of their ZEV investment commitments. Infrastructure investment makes up between 0.4% and 3.1% of the total per-vehicle investment amount, depending on the manufacturer. Some manufacturers headquartered in the United States and Europe are co-investing in charging networks and partnerships with charging companies. Mercedes-Benz plans to accelerate its global fast-charging network, including in North America with MN8, with investment of over $1 billion. This is an addition to Mercedes-Benz's ongoing efforts, including investment in the IONITY charging network in Europe and building public charging at the company's sites. These are translated into an investment of $31 per vehicle sold dedicated to charging infrastructure. GM and VW trail behind with investment of $24 and $15 per vehicle sold, respectively. GM announced that it will invest around $750 million in North America through 2025 to focus on expanding charging for residences, workplaces, and public areas through several programs, including the GM Charging Infrastructure initiative, the EVgo partnership, and the Dealer Community Charging program. In terms of cumulative investment, VW has the largest amount, with over $1 billion dedicated to charging infrastructure across its biggest markets. In Europe, VW plans to invest approximately $420 million (€400 million) in the form of strategic partnerships to accelerate public fast charging, and this is in addition to the IONITY charging network effort. VW also announced a $450 million investment in Electrify America in partnership with Siemens, to accelerate fast charging to 10,000 chargers across 1,800 locations by 2026 in North America, and a joint venture with CAMS to reach 17,000 fast charging points by 2025 in China. Other manufacturers such as BMW ($6/vehicle), Ford ($4/vehicle), and Hyundai-Kia ($2/vehicle) have also shown commitment to supporting charging infrastructure development in specific regions such as co-investment in the IONITY charging network in Europe.

5.3 Executive compensation alignment

The executive compensation alignment metric is an indicator of the degree of alignment between CEO compensation and EVs. Corporate executives can be motivated by the way their compensation is structured. Historically, most CEO compensation packages have been linked to short-term financial performance indicators like earnings before interest and taxes and free cash flow, but the investment in the zero-emission transition is a long-term investment and it cannot be reflected as much in the short-term financial performance as the profits generated by traditional ICEVs can. Therefore, tethering CEO compensation to short-term profits is likely to promote more sales of ICEVs and runs counter to the long-term investments—and delayed revenue payoffs—required to accelerate the transition to ZEVs.

METHODOLOGY

The evaluation for this metric was conducted in collaboration with Valens Research, an investment research firm that provides insights for institutional and individual investors around accounting analytics and corporate valuation as it is linked to corporate performance. Valens Research developed a dataset specifically for this rating that defines the mechanism and elements used by each manufacturer to determine the compensation of their chief executive. The information was extracted from the proxy statements and other public filings of each manufacturer. A proxy statement contains the information the Securities and Exchange Commission requires companies to provide to shareholders so they can make informed decisions about matters that will be brought up at an annual or special stockholder meeting. Proxy statements are issued by companies annually and usually include key topics to be voted on by shareholders as well as information on executive and board compensation and other data. The proxy statements and other relevant reports reviewed for this rating were statements that reflect the compensation structure for fiscal year 2022 or the latest year available for each automaker.

The compensation of the chief executive of a company is usually made up of two types of incentives in addition to fixed compensation, if any: short-term incentives and long-term incentives. Generally, short-term incentives are awards that are provided over a period of 1 year. Long-term incentives are usually provided to induce an executive to achieve results 3 years or more in the future. There are cases where the entire compensation package is determined solely by short-term incentives or long-term incentives. Companies usually set several metrics under each type of incentive included to determine the compensation amount.

For this metric, we evaluate the percentage of compensation that directly depends on ZEV or EV development. Besides the parameters that are clearly linked to EVs, we also give partial credit for parameters associated with CO_2 emissions and ESG factors, as these elements are influenced by progress in EVs. The adjustment factor for CO_2 emissions is 50% because electrification is one of the ways to achieve CO_2 emission targets. The adjustment factor for ESG targets is 33% because environmental issues are one-third of the broader ESG consideration.

We first identify the type of incentives that are linked to EVs, CO_2 emissions, or ESG for the compensation or remuneration of the CEO or equivalent officer at each automaker, if any. Then we calculate the percentage of the executive compensation that is determined by the element. Tesla and BYD, which have already chosen to only produce and sell EVs, get a default number of 100% because their growth and profits all come from EVs.

We convert the final value of the adjusted compensation percentage to a 100-point scale using Equation (1). The manufacturer (excluding Tesla and BYD) with the highest percentage of executive compensation linked to EVs receives a score of 100 and the least ambitious receives a score of zero. Per Equation (1), the executive compensation packages of the other manufacturers are scored relative to the best and worst performers, and they receive a score between zero and 100.

RESULTS

Besides BYD and Tesla, five manufacturers have incorporated EV progress into CEO compensation structure. Table 5 summarizes the EV-related metrics for each, including related elements, the detailed weight in the compensation, whether the company is an EV-only company, and the final score.

At Stellantis, 10% of the long-term incentive plan is linked to EVs and another 10% is linked to compliance with CO_2 emission standards. Stellantis also has a transformation incentive from 2021 to 2025 (22% of the annual compensation) that is determined by a set of milestones related to EV and other technology targets, such as autonomous vehicle technology. BMW uses sales of EVs and CO_2 emissions reduction as the performance criteria to determine the strategic focus target component of its share-based remuneration; half of the performance bonus is also linked to ESG. GM has added an EV element that determines 15% of the long-term incentives (71% of the total compensation portfolio) since 2022. Renault's long-term incentive is determined by four factors, including the sales mix of "electrified passenger cars"[7] in Europe; therefore, the EV element is 25% of the long-term incentive. At Nissan, 5% of the performance-based cash incentive is determined by carbon neutrality and EV development is specifically mentioned, but this element only affects 1.4% of the total compensation. VW and Mercedes-Benz have their executive compensation linked to ESG, but not specifically about EVs. Both Hyundai and Kia mention in their sustainability reports that executive compensation is linked to ESG, but there are no details of the percentage of the impact and thus this could not be scored.

Other manufacturers still have long-term incentives mainly based on financial indicators like free cash flow, adjusted relative return on invested capital, relative total shareholder return, consolidated operating margin, net income, and more.

7 Although "electrified passenger cars" are not defined in the document, as Renault has set targets to sell only ZEVs in Europe, we assume that "electrified" vehicle here does not include non-plug-in hybrids.

Table 5. Metric scores for executive compensation alignment with EV development

OEM	Element in executive compensation		Percentage of total compensation after adjustment	Score
	Linkage	Description[a]		
BYD	EV-only manufacturer			**100**
Tesla	EV-only manufacturer			**100**
Stellantis	EV	50% of transformation incentives (22%) 10% of long-term incentives (52%)	18.7%	**100**
	CO_2 emissions	10% of long-term incentives (52%)		
BMW	EV	50% of share-based remuneration's strategic focus target (17%)	15.0%	**80**
	CO_2 emissions	50% of share-based remuneration's strategic focus target (17%)		
	ESG	50% of performance bonus (15%)		
GM	EV	15% of long-term incentives (71%)	10.7%	**57**
Renault	EV	25% of long-term incentives (28%)	7.0%	**37**
	CO_2 emissions	20% of co-investment plan (0.3%)		
VW	ESG	50% of annual bonus (33%)	4.9%	**26**
Mercedes-Benz	ESG	25% of annual bonus tied (30%)	2.3%	**12**
Nissan	EV	5% of performance-based cash incentives (28%)	1.4%	**7**

[a] Percentages in parentheses reflect the size of that compensation element in the total compensation portfolio.

6

FINAL RATING RESULTS AND DISCUSSION

6 FINAL RATING RESULTS AND DISCUSSION

This report assesses the world's top 20 automakers in the context of the global vehicle market's transition to ZEVs. The companies that successfully navigate the transition are expected to be best positioned for success in a decarbonized future.

Table 6 shows the final ratings of the 20 manufacturers evaluated, including their rating on each of the 10 metrics considered. The final rating score and the total score for each pillar (market dominance, technology performance, and strategic vision) are shown in colors, with the leaders in green (leaders are within the top third of the ratings, 66.7–100), the transitioners in yellow (those rated from 33.4 to 66.6), and the laggards in red (0–33.3). The final rating is calculated by averaging the scores of the three pillars.

The broad range of metrics in the evaluation is important because the ZEV transition is complex. The market dominance pillar reflects how far along each automaker is in transitioning to ZEVs in its own fleet. The technology performance pillar combines an assessment of how well an automaker's offerings can appeal to a growing ZEV consumer base with evaluation of progress in sustainable manufacturing and sourcing, which will be necessary for a fully decarbonized transportation sector. The strategic vision pillar reveals each company's commitment to its own ZEV future.

Many of the automakers score well in at least some areas of our assessment. This suggests the industry has varying strategies for the ZEV transition. **Tesla** has only produced ZEVs since its inception and tops the list on technology attributes that improve the consumer experience: energy consumption, charging speed, and driving range. **BYD** is on the cusp of reaching 100% EV sales share, but still 49% of its fleet is PHEVs with gasoline engines, and to fully transition, BYD will need to phase out its PHEVs. A number of other manufacturers, including **Chang'an**, **Geely**, **SAIC**, **Stellantis**, and **VW**, lag in current ZEV sales but have made greater progress in offering models across more vehicle classes, which can allow them to appeal to a wider range of potential consumers. **BMW**, **VW**, and **Mercedes-Benz** have invested in transitioning to 100% renewable electricity, and several manufacturers are working on making battery production more sustainable. Nine automakers have 100% ZEV targets for 2035 or earlier for at least one brand in leading markets, including for the present (**Tesla**), 2025 (**Tata**'s Jaguar), 2030 (**Geely**'s Volvo, **Toyota**'s Lexus, and **VW**'s Bentley), and 2035 (**BMW**-Mini, **Ford**, **GM**, and **Mercedes-Benz**). Overall, we find that only two manufacturers, **Tesla** and **BYD**, are leaders, and 12 automakers are transitioners making strides in the ZEV transition. The remaining six companies are rated much lower and thus are considered less well positioned at the end of 2022 to capitalize on the changing LDV market.

Every automaker has work to do. Only half of the automakers have reached just 10% or more in ZEV sales share. With our estimates showing that a 77% ZEV sales share is needed by 2030 to stay on track with Paris Agreement climate goals, most of the world's top automakers have ground to cover in the next several years. Even **Tesla**, which scores highest in ZEV sales share and in most of the metrics, needs to significantly expand its offerings of ZEV models to expand its market share. Many of the automakers, especially those headquartered in China, will need to improve on the technology features important to consumers, including energy consumption, driving range, and charging speed. Few of the automakers are advanced in the process of moving toward decarbonized production chains with 100% renewable electricity, and,

Table 6. Overall scores, The Global Automaker Rating 2022

	2022 rating		MARKET DOMINANCE			TECHNOLOGY PERFORMANCE						STRATEGIC VISION			
			ZEVe sales share	ZEV class coverage	Pillar score	Energy consumption	Charging speed	Driving range	Renewable energy	Battery recycle/ repurpose	Pillar score	ZEV target	ZEV investment	Executive compensation	Pillar score
Tesla	83	LEADERS	100	38	69	100	100	100	0	100	80	100	100	100	100
BYD	73	LEADERS	69	88	78	74	38	73	0	100	57	70	79	100	83
BMW	56	TRANSITIONERS	12	50	31	72	52	76	100	92	78	72	20	80	57
VW	53	TRANSITIONERS	10	88	49	60	51	82	75	49	63	92	23	26	47
Stellantis	50	TRANSITIONERS	8	88	48	28	36	28	0	98	38	81	9	100	63
Geely	48	TRANSITIONERS	23	88	55	45	32	68	9	100	51	71	46	0	39
Renault	47	TRANSITIONERS	11	75	43	49	13	32	0	90	37	100	45	37	61
Mercedes-Benz	45	TRANSITIONERS	10	63	36	55	41	73	50	43	53	96	34	12	47
GM	45	TRANSITIONERS	2	38	20	53	31	78	0	99	52	96	36	57	63
SAIC	44	TRANSITIONERS	31	100	65	49	0	0	0	90	28	37	81	0	39
Great Wall	38	TRANSITIONERS	10	75	43	55	15	30	0	100	40	92	5	0	32
Ford	38	TRANSITIONERS	4	25	14	26	49	95	14	91	55	96	36	0	44
Hyundai-Kia	38	TRANSITIONERS	8	63	35	32	75	73	11	100	58	39	20	0	20
Chang'an	36	TRANSITIONERS	16	88	52	45	4	19	0	0	13	68	56	0	41
Toyota	30	LAGGARDS	1	63	32	43	35	70	6	59	43	39	7	0	15
Honda	28	LAGGARDS	0	38	19	51	26	52	0	32	32	73	24	0	32
Nissan	27	LAGGARDS	4	63	33	19	12	29	0	31	18	60	24	7	31
Tata	27	LAGGARDS	6	25	15	87	3	21	6	87	41	52	18	0	23
Mazda	10	LAGGARDS	1	13	7	0	19	3	0	0	4	30	25	0	18
Suzuki	0	LAGGARDS	0	0	0	N/A	N/A	N/A	0	0	0	0	0	0	0

although some show more progress on battery recycling than others, all of them will need to greatly expand in this area in the future. Several automakers, especially those headquartered in Japan, Korea, and India, need a clearer and stronger strategy for ZEVs with targets and investment. We also find that few companies utilize a potentially powerful tool: executive compensation. While **Tesla** and **BYD** got scores of 100 on this metric because the two businesses already sell exclusively EVs, we find that only **Stellantis**, **BMW, GM**, **Renault**, and **Nissan** explicitly tie the pay of their top executives to EVs.

The six laggards include all five Japan-headquartered manufacturers and one headquartered in India, Tata. **Toyota** was the largest LDV manufacturer in the major markets in 2022 and it is in the bottom six of the rating. Alone among the automakers, Toyota has invested heavily in FCEVs, which were 15% of its ZEV sales in the six regions in 2022 (fewer than 4,000 vehicles). FCEVs were not fully assessed here and their energy consumption and charging speed were not rated or compared with those of BEVs because of the stark differences in technology. Nonetheless, we believe that this choice does not significantly influence our results because FCEVs generally perform much better in charging speed and much worse in energy consumption than BEVs. If FCEVs account for a bigger share of the overall ZEV market in the future, we will reconsider our methodology.

This report stands alone as a robust, data-driven, publicly available assessment of global automakers' actions and investment in the ZEV transition. Many other ratings reports are broad, covering thousands of companies across industries, but lack rigor and specificity in their metrics. Unlike many other ratings, this report is not an ESG rating. Some reports, including Eupedia (Hay, 2020) and CSRHub (CSRHub, 2022), simply combine data from other ratings reports. Others such as the S&P Global Environmental, Social, and Governance Scores (S&P Global, 2022) and the Carbon Disclosure Project (Carbon Disclosure Project, 2022) rely at least in part on optional automaker engagement. In contrast, while our choice of metrics and assessment of such metrics reflects the subjective views of the ICCT, this analysis is based on data that is quantitative, transparent, and specific to ZEVs. The data used in our metrics are from either publicly available sources or proprietary databases and were collected using a consistent methodology; we also invited automakers to review company-specific information. We present our full methodology and detail all our data sources. In addition, our rating incorporates real-world data. We account for the average real-world electric drive share of PHEVs and aim to include real-world data on other ZEV aspects in future reports.

We will update and publish this rating annually. The relevant progress made by automakers will be reflected in the next reiteration of their ratings. As we wrap up and publish this report in 2023, there are new announcements and actions from manufacturers regarding their ZEV development. For example, in January 2023, Suzuki announced an investment of $35 billion in BEV targets for Japan, Europe, and India by 2030 (Suzuki, 2023). In March 2023, VW brand increased its 2030 BEV sales target for passenger cars from 70% to 80% (VW, 2023).Due to the rapid pace of development, we expect to see changes in the next iteration of this report. As automakers innovate and improve their ZEV offerings, reduce their upstream emissions, and invest in a ZEV future, the bar will be raised. Additionally, whether a manufacturer has missed any targets it set could be considered in future ratings. As it becomes more feasible to recycle batteries and phase out all fossil fuels in auto manufacturing, we might incorporate those elements into our rating.

This rating is holistic, but not comprehensive. With existing data, it is not possible to craft metrics related to things such as low-emission material sourcing, ZEV safety, and ZEV advertising. We expect our rating framework and the data used in this evaluation to evolve over time as the automakers make more progress and as more data becomes available. We could, for instance, incorporate real-world energy consumption, driving range, and charging data, rather than laboratory data, in future reports when those data become available.

7

CONCLUSIONS

7 CONCLUSIONS

Having rated the world's top 20 automakers in terms of market dominance, technology performance, and strategic vision, we draw the following conclusions:

- **Two automakers clearly lead the pack of global manufacturers in the ZEV transition: Tesla and BYD**. Tesla has always been a BEV-only manufacturer and in March 2022, BYD transitioned from producing a mix of ICEVs to now only producing BEVs and PHEVs. Note, though, that almost half of the vehicles BYD produced in 2022 were PHEVs.
- **Automakers are using different strategies for the ZEV transition.** Some manufacturers, including SAIC, Chang'an, Geely, VW, and Stellantis, are already offering ZEV models across the LDV spectrum from subcompact to pick-up trucks. BMW, VW, and Mercedes-Benz are early investors in moving entirely toward renewable electricity. Nine manufacturers have thus far set targets for 100% ZEV sales by or before 2035 for at least one brand in the leading markets.
- **Every automaker has work to do.** Despite great progress through 2022, this report identifies opportunities for every major global automaker to improve upon its ZEV market development, technology performance, and strategic vision. Even Tesla, which received the highest overall score, can improve its rating by expanding class coverage and moving to 100% renewable electricity. Many of the automakers need to improve vehicle technology in ways important to consumers, such as energy consumption and charging speed. The laggards, all five of the manufacturers headquartered in Japan and one headquartered in India, must work to catch up to competitors in the transition.

This rating report will evolve as the ZEV industry develops. We intend to publish this review annually and to update metrics and benchmarks as the industry changes. We will aim to incorporate more real-world data and information on supply chain sustainability as it becomes available.

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APPENDIX A. DATA PROCESSING AND SOURCES

To assess the performance of the top 20 automakers in the zero-emission vehicle (ZEV) transition, we created a database that includes sales data for all light-duty vehicles (LDVs) sold in 2022 by power train in six global markets: the United States, Korea, Japan, Europe, India, and China. The database also includes vehicle specifications of the electric vehicle (EV) models offered by the top 20 automakers in 2022.

To maximize coverage and accuracy, we compiled vehicle data from multiple sources. The data regarding global vehicle sales and vehicle power train type were derived from four sources for new vehicles sold in 2022: U.S., Korea, and Japan data from MarkLines (MarkLines, 2022); Europe data from Dataforce (Dataforce, 2022), including vehicle sales in the European Union, the EFTA (European Free Trade Association) member states, and the United Kingdom; India data from Segment Y (Segment Y, 2022); and China data provided by ZEDATA (ZEDATA, 2022). The data on ZEV specifications (gross vehicle weight rating, gross weight and curb weight, gross and net battery capacity, energy consumption, driving range, and charging time) of each model were collected from major EV information hubs including ev-database.org, evspecifications.com, and EV-Volumes for models sold in the United States, Korea, Japan, Europe, and India; yiche.com and autohome.com for models sold in China; and from brochures on manufacturers' official websites.

As this study centers on LDVs, we include light-duty commercial vehicles. To eliminate medium- and heavy-duty commercial vehicles from our database, we applied an upper threshold of 3,500 kg for non-U.S. light commercial vehicles (LCVs) and 3,800 kg for U.S. LCVs, because the definition of LCVs in the United States is a bit broader than it is in the other markets.

For joint ventures in China where manufacturers not headquartered in China collaborate with a China-headquartered counterpart under a technology-sharing agreement, we distinguish vehicles that are manufactured as non-domestic or domestic brands and count the sales toward the corresponding controlling corporate entity. This was done across various data sources. For instance, although Buicks sold in China are produced by SAIC, we attributed their sales to GM because Buick is a GM brand and its models are mainly designed and determined by GM. Table A2 lists the top 20 manufacturers and their major brands.

To match the vehicle specification database with the EV sales database, we used model-level matching instead of variant-level matching; this is because sales information was not available at the variant level across all six regions. In cases where a model had multiple variants with different specifications, including things such as battery size and range, we calculated the average of all variants to obtain the representative model specification.

Table A1. Manufacturer reports and public resources used in the rating.

OEM	Sustainability report	Other sources
BMW	2022 BMW Group Report 2021 BMW Group Report & 2021 BMW Brilliance Automotive Sustainability Report	2021 remuneration report BMW.com, Sustainability, Driving electric mobility forward Electrive, Mini to be an all-electric brand by 2030 (March 2021)
BYD	2021 Corporate Social Responsibility Report	2022 Interim Report Baidu, BYD announced that it has stopped producing fuel vehicles from March 2022 (April 2022)
Chang'an	2021 Corporate Social Responsibility Report	OFweek, Chang'an's 2025 goal: new energy accounts for 35% (August 2021)
Ford	2022 Integrated Sustainability and Financial Report	2022 Proxy Statement *COP26 Transport Declaration* (November 2021)
Geely	2021 Environmental, Social and Governance Report (Geely)	OFweek, Geely Automobile's 2025 goal (November 2021)
	2021 Annual and Sustainability Report (Volvo Cars)	Volvo Cars press release, Volvo Cars to be fully electric by 2030 (March 2021)
GM	2022 Sustainability Report 2021 Sustainability Report & 2021 GM China Sustainability Report	2022 Proxy Statement *COP26 Transport Declaration* (November 2021)
Great Wall	2021 Corporate, Social, and Responsibility Report	Chuanchai Securities, Great Wall Motors releases 2025 strategic goals (June 2021)
Honda	2022 Sustainability Report	U.S. Securities and Exchange Commission Form 20-F (2022) Honda press release, Summary of Honda global CEO inaugural press conference (April 2021)
Hyundai-Kia	2022 Sustainability Report (Hyundai)	Hyundai Motor Group news, 2022 CEO investor day (March 2022)
	2022 Sustainability Report (Kia)	Kia press release, Kia CEO investor day – Kia presents 2030 roadmap to become global sustainable mobility leader (March 2022)
Mazda	2022 Sustainability Report	Corporate governance report (2022) Mazda.com, Mazda's approach to electrification.
Mercedes-Benz	2022 Sustainability Report 2021 Sustainability Report	2022 remuneration report 2022 *COP26 Transport Declaration* (November 2021)
Nissan	2022 Sustainability Report	Financial Information as of March 31, 2022 Nissan press release, Nissan unveils Ambition 2030 vision to empower mobility and beyond (November 2021)
Renault	2021-2022 Integrated Report	Universal registration document 2022 Reuters, Exclusive: Renault, Nissan, Mitsubishi to unveil 2030 EV plan this week (January 2022)
SAIC	2021 Annual Report	
Stellantis	2021 Sustainability Report	U.S. Securities and Exchange Commission Form 20-F (2022) Stellantis press release, Dare forward 2030: Stellantis' blueprint for cutting-edge freedom of mobility (March 2022)
Suzuki	2022 Sustainability Report 2021 Sustainability Report	Corporate governance report (2023)
Tata	2021-22 Integrated Annual Report	*COP26 Transport Declaration* (November 2021) Forbes, Jaguar to turn all electric by 2025, Land Rover EVs start in 2024 (February 2021) *The ZEV target for the Tata brand was obtained from direct communication with Tata and is less ambitious than the latest publicly available target.*
Tesla	2021 Impact Report	
Toyota	2022 Sustainability Report	U.S. Securities and Exchange Commission Form 20-F (2022) Toyota, Media briefing on battery EV strategies (December 2021)
VW	2022 Sustainability Report 2021 Sustainability Report	Remuneration report 2022 InsideEVs, Audi will go electric from 2033 but not in China (June 2021) Porsche press release, Porsche's ambition for 2030: More than 80 percent all-electric new vehicles (March 2022) ŠKODA story board, ŠKODA in 2030? More electrified, more digital (June 2021) Volkswagen press release, Bentley Motors outlines Beyond100 strategy, targeting sustainable luxury mobility leadership (November 2020) Volkswagen press release, Volkswagen is accelerating transformation into software-driven mobility provider (March 2021)

Table A2. List of top 20 manufacturers and major brands

OEM	Major brand
Toyota	Toyota, Daihatsu, Hino, Lexus
VW	Audi, Bentley, Bugatti, Cupra, Jetta, Lamborghini, MAN, Porsche, SEAT, Škoda, Volkswagen
Hyundai-Kia	Genesis, Hyundai, Kia
Stellantis	Abarth, Alfa Romeo, Chrysler, Citroen, Dodge, DS, Fiat, Fukang, Jeep, Lancia, Maserati, Opel/Vauxhall, Peugeot, Ram
Honda	Honda, Acura
GM	BrightDrop, Buick, Cadillac, Chevrolet, GMC
Ford	Ford, Lincoln
Nissan	Nissan, Datsun, Infiniti
Suzuki	Suzuki, Maruti
BMW	BMW, Mini, Rolls-Royce
SAIC	Baojun, Clever, IM Motors, Maxus, MG, Roewe, Wuling (SAIC), Yuejin
Mercedes-Benz	Mercedes-Benz, Mercedes-Maybach, Smart
Geely	Geely, Geometry, LEVC, Livan, Lotus, LYNK & CO, Maple, Ouling, Polestar, Volvo Cars, Yuancheng, Zeekr
Renault	Renault, Alpine, Dacia, Ezoom
Chang'an	Chang'an
BYD	BYD, Denza
Tesla	Tesla
Tata	Tata, Jaguar, Land Rover
Great Wall	Great Wall, Haval, Ora, Tank, Wey
Mazda	Mazda

APPENDIX B. SUPPLEMENTARY DATA FOR METRIC SCORING

B.1 ZEV-EQUIVALENT SALES SHARE

Table B1 details the ZEV-equivalent sales share of each manufacturer across the six major markets and shows their total ZEV and PHEV sales shares globally. The final score of the ZEV-equivalent sale share metric is calculated from the ZEV-equivalent share for each automaker, and the final score is shown in the rightmost column.

Table B1. ZEV-equivalent sales share by manufacturer and region

OEM	ZEV-equivalent share						Global				Score
	China	U.S.	Europe	Japan	India	Korea	ZEV	PHEV	Discounted PHEV	ZEV-equivalent	
Tesla	100%	100%	100%				100%			100%	100
BYD	69%			19%*	27%*		49%	49%	19%	69%	69
SAIC	30%		54%		9%*		30%	2%	1%	31%	31
Geely	19%	22%	40%	7%*	0.2%*	25%*	19%	11%	3%	23%	23
Chang'an	16%						15%	3%	1%	16%	16
BMW	6%	8%	20%	5%	1%*	9%	10%	10%	3%	12%	12
Renault	99%*		12%	—	—	1%*	11%	1%	0.3%	11%	11
Great Wall	10%		21%*				10%	1%	1%	10%	10
Mercedes-Benz	5%	4%	18%	4%*	1%*	8%	8%	8%	3%	10%	10
VW	5%	8%	14%	2%*	0.2%*	11%	9%	4%	1%	10%	10
Stellantis	16%	1%	13%	3%*	—	8%*	7%	5%	1%	8%	8
Hyundai-Kia	0.5%*	4%	18%	92%*	0.2%*	11%	7%	2%	1%	8%	8
Tata	1%*	1%*	11%	1%*	6%	0.04%*	5%	3%	1%	6%	6
Nissan	0.2%*	2%	14%	8%	—		4%			4%	4
Ford	2%*	3%	5%	—		0.2%*	3%	2%	1%	4%	4
GM	4%	2%	0.2%*	—		7%*	2%	0.3%	0.1%	2%	2
Mazda	0.3%*	0.1%*	7%	0.1%*			1%	2%	1%	1%	1
Toyota	0.4%*	0.7%	3%	0.3%	—	2%*	0.4%	1%	0.4%	1%	1
Honda	1%	0.02%*	3%*	0.1%*	—	—	0.3%	0.4%	0.1%	0.5%	0
Suzuki			1%*	—	—		0%	0.1%	0.03%	0.03%	0

Note: Asterisks signify that the OEM's total ZEV-equivalent sales in the respective region were less than 5,000. Cells shaded in grey indicate that no light-duty vehicles (LDVs) were sold in that market and cells filled with a dash denote that no EV sales occurred in that market.

B.2 ENERGY CONSUMPTION

Table B2 compares the sales-weighted average adjusted energy consumption before and after the adjustment by curb weight, and the final score for the energy consumption metric for each automaker. Automakers are ordered from top to bottom starting with the lowest sales-weighted average energy consumption for their 2022 BEV sales.

Table B2. Sales-weighted fleet-average energy consumption of BEVs by manufacturer

OEM	Average WLTP energy consumption (Wh/km)		Score
	Before adjustment	After adjustment	
Tesla	133	124	100
Tata	116	130	87
BYD	132	136	74
BMW	151	137	72
VW	158	143	60
Great Wall	124	145	55
Mercedes-Benz	161	145	55
GM	140	146	53
Honda	140	147	51
Renault	123	148	49
SAIC	102	148	49
Geely	157	150	45
Chang'an	116	150	45
Toyota	159	151	43
Hyundai-Kia	161	156	32
Stellantis	141	158	28
Ford	176	159	26
Nissan	146	162	19
Mazda	168	171	0
Suzuki			

B.3 CHARGING SPEED

Table B3 shows the sales-weighted average charging speed for each automaker for BEVs that do not support fast charging and BEVs that support fast charging, and the sales share of each BEV group for each automaker. Additionally, the table summarizes the sales-weighted average charging speed considering the maximum average charging speed from BEV models of each automaker and their final scores for this metric.

Table B3. Average charging speed breakdown by normal-charging capable only and fast-charging capable BEVs, by manufacturer

OEM	Average charging speed (kW)		Percentage of BEV sales		Sales-weighted average charging speed (kW))	Score
	Normal-charging capable only	Fast-charging capable	Normal-charging capable only	Fast-charging capable		
Tesla		172		100%	172	**100**
Hyundai-Kia	11	135	0.3%	100%	134	**75**
BMW		98		100%	98	**52**
VW		96		100%	96	**51**
Ford		93		100%	93	**49**
Mercedes-Benz	3	94	15%	85%	81	**41**
BYD		76		100%	76	**38**
Stellantis	2	77	6%	94%	73	**36**
Toyota	2	77	6%	94%	72	**35**
Geely	3	67	0.001%	100%	67	**32**
GM		65		100%	65	**31**
Honda		58		100%	58	**26**
Mazda		47		100%	47	**19**
Great Wall	3	42	1%	99%	41	**15**
Renault	12	44	17%	83%	38	**13**
Nissan		36		100%	36	**12**
Chang'an	1	35	32%	68%	24	**4**
Tata	6	25	14%	86%	22	**3**
SAIC	2	61	73%	27%	18	**0**
Suzuki						

B.4 ZEV INVESTMENT

Table B4 details the cumulative investments in ZEVs announced by each manufacturer from 2016 to 2022, the investment values in 2022 U.S. dollars, the total vehicle sales in 2022, and the resulting investment per vehicle and metric scores.

Table B4. Cumulative ZEV investments by manufacturer

OEM	Total EV investment (million US$)	Total EV investment (million 2022 US$)	Adjustment factor from EV to ZEV	ZEV investment per vehicle (million 2022 US$)[a]	Score
Tesla	35,000	35,065	1.00	2,929	100
SAIC	43,500	42,193	0.95	2,364	81
BYD	43,535	44,663	0.70	2,305	79
Chang'an	23,140	23,569	0.94	1,642	56
Geely	30,761	31,264	0.75	1,352	46
Renault	22,100	20,616	0.93	1,322	45
Ford	50,000	47,722	0.68	1,069	36
GM	36,000	33,813	0.92	1,055	36
Mercedes-Benz	32,500 [b]	30,452	0.64	1,013	34
Mazda	10,800	9,397	0.52	732	25
Nissan	17,600	16,596	1.00	724	24
Honda	40,000	34,114	0.64	714	24
VW	57,000	53,573	0.78	690	23
Hyundai-Kia	38,500 [b]	36,607	0.81	610	20
BMW	16,500 [b]	18,725	0.63	593	20
Tata	6,800 [b]	6,987	0.74	538	18
Stellantis	17,750 [b]	16,941	0.69	273	9
Toyota	35,000	31,165	0.48	220	7
Great Wall	1,550	1,479	0.95	152	5
Suzuki	1,035	988	0.31	13	0

[a] A 10-year recovery period is assumed for all investments.
[b] We assumed an equal split of the total investment when a manufacturer's commitment included other future technologies (e.g., autonomous driving technology).

APPENDIX C. METHODOLOGY DETAILS

C.1 REAL-WORLD ELECTRIC DRIVE SHARE ESTIMATION

We estimated real-world electric drive share based on the range of each PHEV model when driving in charge-depleting mode, which is typically related to all-electric range. Data on the all-electric range or charge-depleting mode range for each PHEV model comes from the EV specification database that we compiled.

Plötz et al. (2022) and Isenstadt et al. (2022) developed the best-fit curves that reflect the relationship between the charge-depleting range and real-world electric drive share in the European Union and the United States, respectively. Utilizing the range data we compiled as inputs, these curves were the basis for our estimates of real-world electric drive share in all six major markets.

To find the electric drive share of PHEVs in China, India, Japan, Korea, and the United States, we used the function and parameters established by Isenstadt et al. (2022) and applied Equation (2) to each PHEV model. The original function and its coefficients were established by the U.S. Environmental Protection Agency (EPA) for determining a PHEV model's utility factor (UF), which represents the share of driving performed in charge-depleting (CD) mode.

$$UF = 1 - \left[\exp\left(-\sum_{i=1}^{k}\left(\frac{CD}{ND}\right)^{i} C_i\right)\right] \qquad (2)$$

where:

CD = range in CD mode in miles

ND = normalized distance (985 miles, estimated by Isenstadt et al. [2022])

C_i = weighting coefficient (summarized in Table C1)

k = number of coefficients

Using engine-off distance traveled collected by vehicle on-board diagnostics systems on California-based vehicles, Isenstadt et al. (2022) revised the normalized distance (ND) to 985 miles, 2.5 times the default value of 399 miles from EPA, to better reflect the real-world electric drive share of U.S. PHEVs. The other coefficients are displayed in the table below.

Table C1. Electric drive share coefficients established by the U.S. EPA

Coef (C_i)	1	2	3	4	5	6	7	8	9	10
Electric drive share for city or highway	13.1	-18.7	5.22	8.15	3.53	-1.34	-4.01	-3.9	-1.15	3.88

We used the same revised parameters from Isenstadt et al. (2022) for China, India, Japan, and Korea, as there is no recent study available targeting these countries. The U.S. PHEV function is from the most recent study on real-world PHEV use, and the analysis was based on automatically collected, direct measurement of drive share with the engine off. In addition, much like in the United States, these countries are primarily dominated by private cars and not the company-owned vehicles that are more common in Europe.

To find the real-world electric drive share of PHEVs in the European Union, we used the function and parameters established by Plötz et al. (2022) and applied Equation (3) to each PHEV model. The original function and its coefficients were established by the European Commission in 2017 to determine a PHEV model's UF, and the functional form is identical to the function used by EPA but with different weighting coefficients.

$$UF = 1 - \left[\exp\left(-\sum_{i=1}^{k}\left(\frac{CD}{ND}\right)^{i} C_i\right)\right] \quad (3)$$

where:

CD = WLTP CD mode range in km

ND = Normalized distance (2,200 km for private or 9,100 km for company cars, estimated by Plötz et al. [2022])

C_i = weighting coefficient (summarized in Table C2)

k = number of coefficients

Table C2. Electric drive share coefficients established by the European Commission

Coef (C_i)	1	2	3	4	5	6	7	8	9	10
Electric drive share for city or highway	26.3	-38.9	-631.05	5964.8	-25095	60380	-87517	75514	-35749	7155

Plötz et al. (2022) revised the normalized distance (ND) and this parameter was estimated separately for private cars and company cars. The authors adjusted ND = 2,200 km for private vehicles and ND = 9,100 km for company vehicles, 2.8 and 11.4 times the default value of 800 km from the European Commission. According to their estimation, electric drive share is significantly lower for company cars. Because our data does not differentiate ownership type, we assumed a 70% and 30% mix between company and private cars for vehicles sold in the European Union (Krajinska, 2023).

C.2 CLASS COVERAGE CATEGORIZATION USING ICEV-EQUIVALENT CURB WEIGHT

We divided the ZEVs in the sales dataset into eight classes based on vehicle length for passenger cars (PCs) and curb weight for LCVs. We used adjusted curb weight for LCV classification. BEVs tend to weigh more because of their batteries, and this can result in inaccurate categorization when directly mapping them into classes designed for ICEVs based on curb weight. To ensure accurate comparisons, we adjusted the curb weight of BEVs to their ICEV counterparts.

To make this adjustment, we obtained curb weight information for 10 ICEV models that have a ZEV counterpart with an almost identical size. We only selected as example models ICEVs that have a ZEV counterpart produced by the same manufacturer and where that manufacturer is among the top 20 manufacturers included in this report.

The ZEV models include both BEVs and FCEVs. The ICEVs' curb weights range from 1,393 kg to 2,261 kg, and the ZEVs' curb weights range from 1,685 kg to 2,558 kg. The ratio between each ICEV and its ZEV counterpart was calculated and resulted in an average ratio of 0.83, which was consistent across models of different curb weights and power trains (standard deviation of 0.034). This average ratio was used as a discount factor to estimate the ICEV-equivalent curb weight of each BEV model, which was found to be a reasonable estimation method for ZEV models with a wide range of curb weights.

Table C3. Curb weight comparison

OEM	ICEV		ZEV		Ratio	ICEV-equivalent curb weight (kg)
	Model	Curb weight (kg)	Model	Curb weight (kg)		
Kia	**Niro**	1,393	**Niro EV**	1,688	0.83	1,405
Hyundai	**Kona**	1,409	**Kona Electric**	1,685	0.84	1,403
Toyota	**Avalon**	1,619	**Mirai (FCEV)**	1,930	0.84	1,607
BMW	**4**	1,623	**i4**	2,123	0.76	1,768
VW	**Tiguan**	1,708	**ID.4**	2,072	0.82	1,725
Audi	**Q5**	1,850	**Q4 e-tron**	2,120	0.87	1,765
BMW	**7**	2,141	**i7**	2,684	0.80	2,235
Mercedes Benz	**S class**	2,150	**EQS**	2,539	0.85	2,114
BMW	**X5**	2,190	**iX**	2,617	0.84	2,179
Ford	**Ford Transit**	2,261	**Ford E-Transit**	2,558	0.88	2,130
Average					**0.83**	

We classified all PCs into five classes (subcompact car, compact car, midsize car, large car, and SUV/MPV) and all LCVs into three classes (small, medium, and large). The length thresholds for PC classification are based on EV-Volumes' global segment classification (EV-Volumes, 2023), and curb weight thresholds for LCV classification are based on the EU N1 subclasses standard for LCV (Vermeulen et al., 2012). We combined mini passenger cars and the subcompact classes to reflect the model availability in the smaller passenger car segment. The detailed weight thresholds are listed in Table C4.

Table C4. ZEV class categorization

Fleet	Class	Standards: Length (m)	Source
PC	**PC – Mini/subcompact**	0 – 4.1	Adapted from EV-Volumes classification[a]
	PC – Compact	4.1 – 4.6	
	PC – Midsize	4.6 – 4.8	
	PC – Large	4.8 -	
	PC – SUV/MPV		
Fleet	**Class**	**Standards: Curb weight (kg)**	**Source**
LCV	**LCV – Small**	0 – 1305	EU N1 subclasses
	LCV – Medium	1,305 – 1,760	
	LCV – Large	1,760 – 3,500[b]	

[a] From EV-Volumes, https://www.ev-volumes.com/.
[b] The upper threshold is 3,500 kg for non-U.S. LCVs and 3,800 kg for U.S. LCVs based on the different regulatory categorization in the United States.

C.3 ENERGY CONSUMPTION ADJUSTMENT

We adjusted the energy consumption of each BEV model to account for weight differences, whic;h inherently affect vehicle energy consumption from a physical perspective. To study the relationship between energy consumption and curb weight, we follow Equation (4) and perform a linear regression analysis, using all BEV models sold by the top 20 manufacturers (3,061 model variants).

$$EC = \alpha + \beta \times Curb\ weight + \varepsilon \tag{4}$$

Here, α is a constant, ε is the error term, and β is the coefficient that estimates on average how much energy consumption will increase for every additional kilogram in curb weight. The result is shown in Table C5. We find that, on average, each kilogram increase in curb weight is correlated with a 0.056 Wh·km-1 increase in energy consumption. This finding is similar with a previous study (Weiss et al., 2020), which investigated 218 electric passenger cars from China, Norway, and the United States and found a correlation of 0.06 Wh·km-1·kg-1.

Table C5. Regression result for energy consumption adjustment

Dependent variable	Energy consumption (Wh/km)
Curb weight (kg)	0.056***
Cons	58.01
N	3061
R-sq	0.37

Note: Three stars (***) denote that the corresponding variable is significant at 0.001 level

C.4 CHARGER DEFINITIONS

We categorize chargers as either normal or fast using the criteria below.

Table C6. Charger type definitions

Type of charger	Power output	Time for charging	Current type
Normal charger	3–7 kW	Slow charging: 7–16 hours (0%–100%)	Alternative current
	11 kW–22 kW	Intermediate charging: 2–4 hours (0%–100%)	Alternative current
Fast charger	50 kW–100 kW	Fast charging: 30–40 minutes (10%–80%)	Direct current
	100+ kW	Ultra fast	Direct current

Source: Adapted from European Court of Auditors (2021).

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