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Kearney, Madrid

Polestar and Rivian pathway report

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Introduction

All industries face a significant challenge over the next decade if we are to meet the goals of the Paris Agreement, and automotive is no exception. Today, passenger vehicle emissions alone account for 15 percent of all greenhouse gas (GHG) emissions globally.[1,2] Recognizing this, the automotive industry has taken steps over the past decade to decarbonize. So far, the primary focus for the industry has rightly been on electrification of the fleet, targeting the significant portion (60 to 65 percent for internal combustion engine (ICE) vehicles) of emissions that come from the tailpipe.[3]

The challenge: when modeling a hypothetical well-to-wheel scenario of **aggressive** battery electric vehicle (BEV) adoption, powered by hypothetical **full switch** to fossil-free power sources in parallel, there is **still** a GHG emission overshoot, unless upstream scope 3 (supply chain emissions) are simultaneously tackled.[4]

This short report looks at well-to-wheel emissions of the projected passenger vehicle fleet globally to 2050, explores the monumental challenges the industry faces, and outlines a suite of actions that merit collective action. Detail on the modeled scenarios, methodology, data, and assumptions can be found in a longer version of this report.

Today, passenger vehicle emissions alone account for 15 percent of all greenhouse gas (GHG) emissions globally.

[1] Calculated life cycle emissions compared to IEA stated global CO_2e emissions in 2021 based on Kearney model
[2] Include all GHG emissions and measured in CO_2e throughout the report
[3] Green nCap, ICCT, Volvo
[4] Emissions from supply chain of fuel extraction and electricity production included

Not a single year to lose

The remaining global emission budget is estimated by IEA to be approximately 500 $GtCO_2$-equivalent ($GtCO_2e$) before 2050 in order to stay below a 1.5-degree Celsius temperature increase.[5] Assuming passenger vehicles maintain an equal share of global emissions (~15 percent, considering total life cycle emissions), this would equate to approximately 75 to 80 Gt of total emissions left for the industry. At the current trajectory this budget will be reached by 2035, which would equate to an overshoot of 75 percent in 2050, based on ICCT optimistic projections (our baseline case)—or larger when applying conservative assumptions.

The numbers above are rightly debated; this is a complex topic. What share of the remaining GHG budget should "passenger vehicles" take? Will efficiency advances in the combustion engine sufficiently drive GHG reduction? What about the energy crisis, the price and efficiency of fossil-free power sources, raw material availability, battery efficiency, and technology yet to be developed?[6] Will different regions transition at a different pace? To support this discussion, scenarios and sensitivity analysis are included in the longer version of this report.

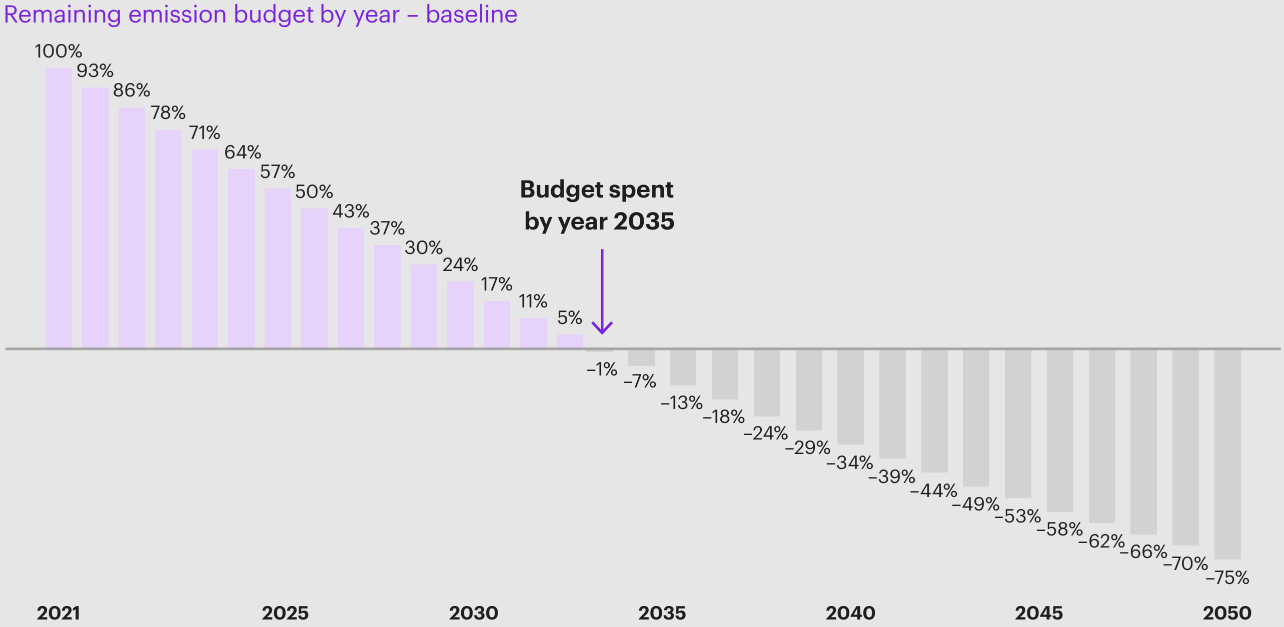
However, whichever way it is modeled, the pathway to 1.5 degrees for the passenger vehicle industry is tight. Few reports project a scenario that is achievable without accelerated action. Certainly, the trajectory is too close for comfort. Every year that passes eats up approximately 7 percent of the GHG budget in the baseline trajectory, implying greater subsequent effort and capital requirements just to play catch-up and amplifying the cost to adjust each year (see figure 1).

[5] IEA Net Zero Emission scenario, budget from 2021 and onward based on IPCC's 50 percent probability of staying within the 1.5-degree target, assuming 40 $GtCO_2e$ in carbon capture within 2050

[6] Renewables (wind, solar, hydro) and nuclear power

Figure 1

Approximately 7 percent of the GHG budget in the baseline trajectory is consumed eachyear



Note: GHG is greenhouse gas.

Source: Kearney analysis

Looking at the **total life cycle emissions** for vehicles (as per available data) and projecting vehicle fleet demonstrates the following:

— Fully switching to BEVs across the entire global car parc will not be enough to stay below 1.5 degrees (lever 1 in this report).

— Fully powering this exclusively BEV fleet with fossil-free energy will also not be enough to stay below 1.5 degrees (lever 2).

— In isolation, significant advances in sustainable production and manufacturing in supply chain will not be enough to stay below 1.5 degrees (lever 3).

The industry needs to simultaneously tackle all three, at an accelerated pace. This conclusion is supported by the modeling output (referred to in the longer report as scenario 1) in figure 2, that a transition to BEVs (lever 1) will only reduce 75 percent overshoot in baseline to 50 percent. Transitioning to BEVs and charging them only with fossil-free energy (lever 2) will further bring down the GHG budget overshoot to 25 percent. A possible but challenging pathway to remain below 1.5 degrees exists when supply chain emissions are reduced (lever 3) along with the two previous levers.

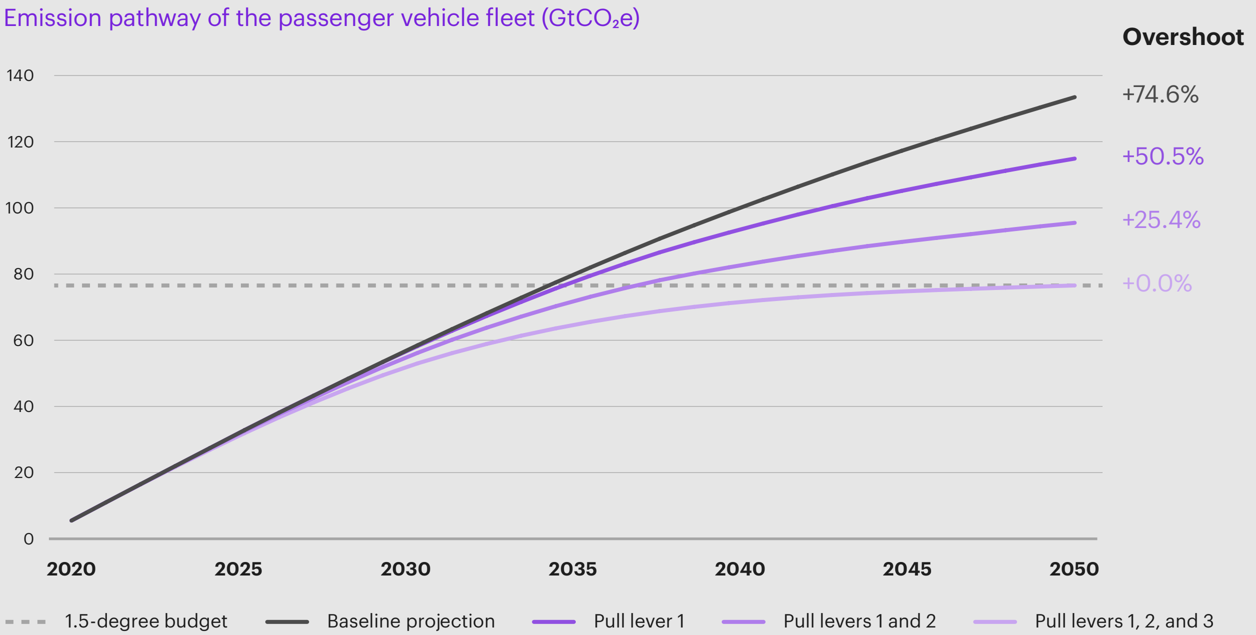
Collective action for collective challenges

In circumstances where there is high strategic alignment, strong ambition between parties, and a high value at stake, collective action and partnerships can drive a step change in results. Competition is healthy, but perhaps the industry needs to redefine where to compete and where to collaborate.

While topics such as portfolio, design, and manufacturing excellence are clear examples of differentiation, tackling scope 3, supporting supply base development, driving consumer shifts, and end-of-life are examples of areas that merit a collective approach.

The following paragraphs outline some of the key areas most significant for all manufacturers. Many are under way already and only need accelerating, some are more accessible than others, and some are new ways of working. None are easy.

Figure 2
The automotive industry must take action in several areas in order to hit 1.5-degree targets



Source: Kearney analysis

Transitioning to zero emission vehicles (ZEVs)

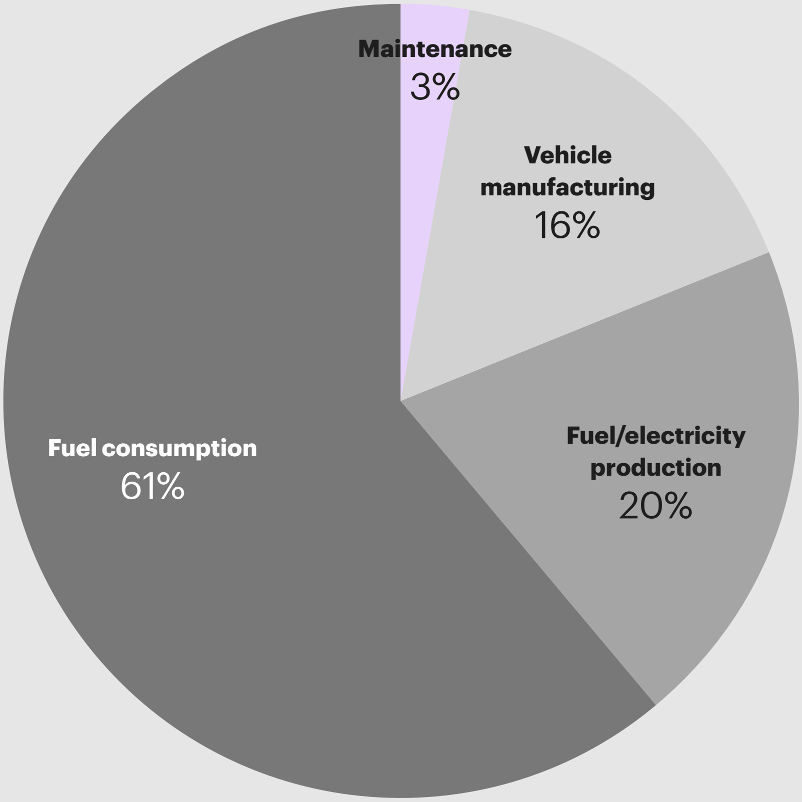
The tailpipe emissions of passenger cars with an internal combustion engine generate 60 to 65 percent of the car's total life cycle emissions (see figure 3). Accordingly, the most significant impact will come from eliminating tailpipe emissions. While other technologies such as various forms of fuel cell show emerging potential, today BEVs are the dominating technology, feasible to deploy at mass scale.

The scale of the challenge, however, is not to be underestimated. To stay on the 1.5-degree pathway for 2050, BEV share of sales must grow from 6 percent to close to 100 percent by 2032. Beyond the immense operational hurdles to overcome, such an ambition level and radical acceleration would also cause significant socioeconomic implications that vary by region, posing challenges especially in regions with high population density and relatively low disposable income.

On the demand side, charging logistics and range anxiety continue to feature as the top two barriers to adoption for BEVs, with cost coming in a close third.[7] Charging infrastructure will be driven by policymakers and broader infrastructure players, but what opportunities exist for manufacturers to work closely with the market players to secure sufficient infrastructure? Partnerships between original equipment manufacturers (OEMs) exist in this area today, demonstrating that collaboration among OEMs and investors can be undertaken to accelerate the infrastructure rollout. **How can the industry drive adoption in these harder to reach areas, where zero emission vehicles will drive a disproportional impact? How can better education of the consumer and transparency in purchasing decisions support this?**

[7] EY Mobility Consumer Index (MCI) 2022 study

Figure 3
Tailpipe emissions of passenger cars with an internal combustion engine account for the overwhelming majority of the car's total life cycle emissions



Sources: Green NCAP, ICCT; Kearney analysis

Fossil-free power provision for use phase

The shift to electric powertrains is only as clean as the power source used to charge the vehicle. At a global level, applying today's global average electricity mix to a new electric fleet generates around 15 to 30 tCO_2e reduction (35 to 46 percent of lifetime emission) for an average vehicle compared to an ICE over an assumed 240,000km lifespan, with the degree of reduction varying significantly by region.

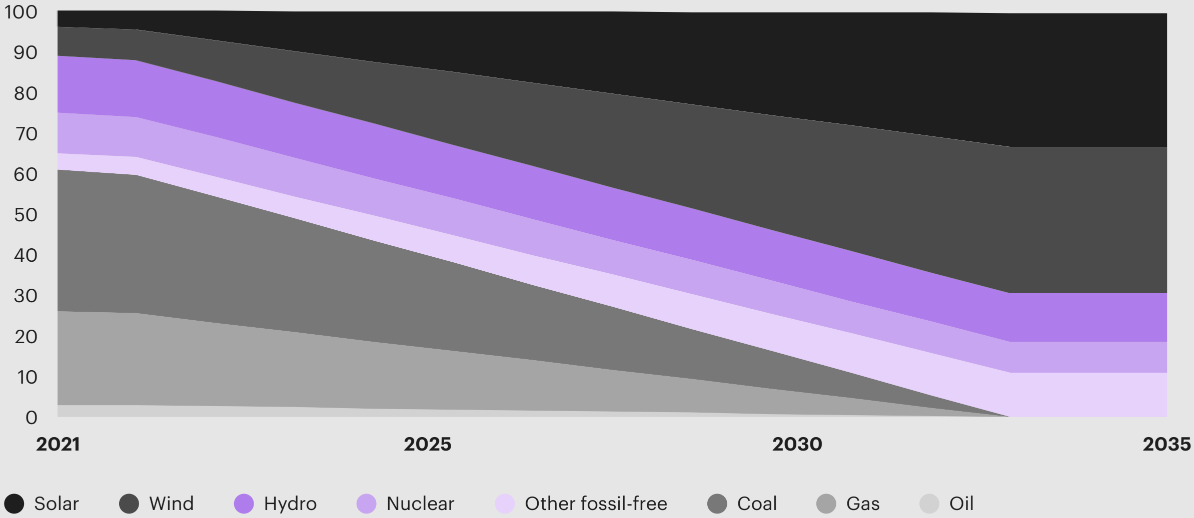
The implication? To stay on a 1.5-degree pathway, in addition to driving BEV adoption, the source power in use phase needs to shift from a global average of 39 percent fossil-free electricity to 100 percent by 2033 (referred to as scenario 1, detailed in the methodology section which starts on page 9; see figure 4). Shifting to BEV and reaching 100 percent fossil-free electricity use by 2033 would enable a reduction of emission overshoot by 2050 from 50 percent to 25 percent. This shift of fossil-free power in the use phase requires additive renewable energy and should take place without the transportation sector using existing renewables from other industries.

Vehicle manufacturers have not historically been in the driver's seat for a fossil-free energy transition but do offer significant consumer-facing opportunities to influence behaviors. Driven by the urgent need for action, some OEMs are looking to ensure fossil-free electricity in the use phase by investing in clean energy, starting up ventures in this space, or teaming up with energy providers. Creative concepts such as bundling vehicle sale with a guarantee of clean energy provision, just as options such as alloys or sound system upgrades are chosen on new builds, is an example of creative thinking not seen today but potentially needed to open up opportunities. **How can we link scope 3 with the initial vehicle sale? How might other shifts or re-bundling of the consumer value proposition unlock further progress here?**

Figure 4

In addition to BEV adoption, the source power in use phase needs to shift to a global average of 100% fossil-free electricity by 2033

Global electricity mix development, fast-tracked IEA net zero emissions (%)



Notes: Adjusted by fast-tracking 100% fossil-free energy to 2033 compared to 2050 in raw data. Assumes linear increase in the relative share of fossil-free electricity. BEV is battery electric vehicle.

Sources: IEA; Kearney analysis

Beyond this, consumer dynamics are shifting and present an opportunity to drive behavioral change to drive further GHG-emission reduction. There is a potential to engage more directly with consumers to influence emissions related to the use phase, such as smart charging to optimize charging at times of the day with an electricity production surplus, to real-time efficiency feedback on driver behavior and habits. With scale, significant proximity, and consumer loyalty to leverage, OEMs have a powerful role to integrate more behavioral nudges into elements such as the dashboard and interfaces to drive systemic change. Through increasing driver awareness with interactive experiences of, for example, current grid impact of charging, optimal charging times, and high-fossil-free electricity usage locations, emissions can be reduced post-sale. **What other opportunities exist for the industry to influence the consumer better with behavioral nudges both in real-time driving feedback and in charging?**

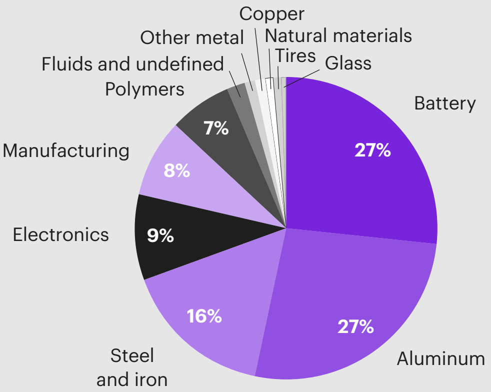
The supply chain

As the transition from ICE vehicles to an electric fleet powered by fossil-free energy takes place, the largest part of the carbon footprint will shift from products in use to supply chain. Today, supply chain emissions for an EV are approximately 35 to 50 percent higher than for ICEs, primarily due to the additional emissions related to the battery (see figure 5).

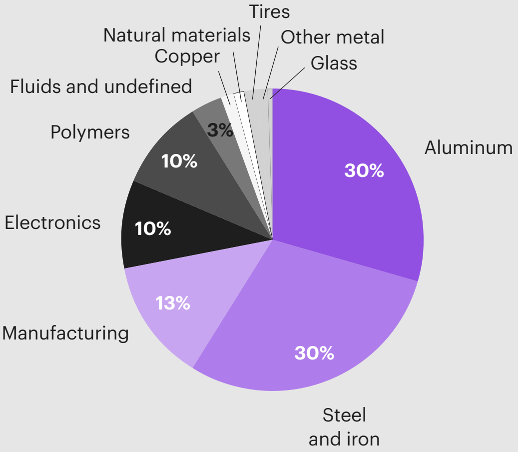
To stay on a 1.5-degree pathway, the manufacturing and supply chain would need to reduce GHG emissions by 81 percent by 2032. This is an enormous task. As indicated in figure 5, the largest footprint comes from batteries, steel and iron, and aluminum used in vehicles, more specifically the amount and type of energy used in manufacturing. The necessary emission reduction in battery production will require 100 percent electrification of cell and pack manufacturing, increased electrification of material extraction and processing, all powered by a fossil-free electricity mix. Other opportunities exist in the development and utilization of low-impact battery chemistries or creating smaller batteries tied to more robust and faster charging networks.

Figure 5
Currently, supply chain emissions for an EV are approximately 35 to 50% higher than for ICEs

BEV
Detailed estimation of GHG impact for **78%** of supply chain emissions (indicated in purple) available in methodology



ICE
Detailed estimation of GHG impact for **73%** of supply chain emissions (indicated in purple) available in methodology



Notes: EV is electric vehicle. BEV is battery electric vehicle. ICE is internal combustion engine. GHG is greenhouse gas.
Sources: Polestar LCA report; Kearney analysis

Steel, iron, and aluminum represent 40 to 60 percent of GHG emissions in passenger vehicle supply chains. Fundamentally there are three ways to approach this—reduction in emissions in material production, reduction in the amount of material used (for example, by optimizing material utilization), or replacement with alternative lower-impact materials. While costly, several technologies exist today to tackle production emissions, for example through use of direct reduced iron-electric arc furnace (DRI-EAF), inert anodes, and carbon capture, as well as fossil-free electricity and fossil-free hydrogen. Tackling the quantity and alternative materials requires a rethink of the front end in the value chain, with an increase across the board on design-for-decarbonization and design-for-circularity thinking. So far, many OEMs have entered individual partnerships with entities such as green steel producers. Some have sought to secure both supply and use the surplus of hydrogen from green steel production to power fuel cell vehicles. Co-investments and other forms of support via joint funding and guaranteed orders are other opportunities to support supplier capacity development and investment that benefit the broader community. **How can the industry send stronger market signals to collectively demand and support scaling of low-carbon alternatives, not only in green steel but in other materials?**

Battery production and end-of-life management remains a challenge. Raw material at the scale needed to drive the accelerated adoption outlined above is not accessible today and extraction is fraught with cost and social challenges. **How can the industry commit to raw material extraction at the lowest possible social cost? What are new ways to reuse and recycle resources within and across industries?**

Establishing common standards, metrics, and criteria are paramount. Internal tools such as supplier emission evaluation criteria and internal carbon pricing to drive new investment decision options are beginning to be adopted, which can accelerate the pace and prepare those who use it for potential future policy requirements. **Can the industry collectively agree on measurements and standards, both in terms of LCA calculations and ESG guidelines in passenger vehicle operations?**

Solutions for reducing upstream scope 3 emissions will inevitably be a mix of opportunities that drive a competitive advantage as well as some opportunity for collective action.

A call to action

Numerous challenges—economic, social, and raw material availability—exist throughout this transition. There are many more variables not covered in this report, including mobility mix, effect of autonomous driving, and sharing models. What is clear is that each scenario modeled is tight and disruptive action is required within the next few years.

The historic conflict between sustainability and profitability is diminishing but still looms large. **We must assign the right value to sustainability and the cost of inaction.**

The investment community certainly is moving, and capital flows are shifting from traditional investment to sustainable investment, recognizing an increasing tie between sustainable transformation and financial benefits. In 2021, global sustainability investments totaled $35.3 trillion, representing more than a third of all assets in five of the world's biggest markets, growing at more than 15 percent annually since 2018.[8]

Consumers are also starting to shift, with sustainability becoming an increasingly important purchasing criterion for passenger vehicles—stated by 61 percent of survey respondents in the Global Sustainability Study in 2021, and especially for the increasingly influential younger generation, with 40 percent of Gen Z and Millennials stating they are willing to pay for greener products and will have stronger purchasing power in the future.[9] The focus on sustainable solutions is only going to get more critical.

The pathway below 1.5 is not easy and all industries face an uphill battle. The passenger vehicle industry has an opportunity to reframe the challenge, reconsider competitive parameters, and step up collective actions to halve GHG emissions by 2030. Debate will continue regarding time frames, data variances, and long-term targets, but the case for action is clear.

This report calls for OEM leaders to jointly come to the table to discuss where opportunities might exist to collaborate on the greatest challenge humankind has faced—the pathway below 1.5 degrees. Every year that passes without significant reductions is an opportunity lost and a setback from which we will have to work even harder to recover. We need to come together to create a plan to tackle the challenge and deliver on that plan as quickly as possible.

Reframe the challenge, invite partners, and accelerate action. The path to a sustainable future lies ahead, and it is up to the industry to set the pace at which one shall travel it.

[8] "Sustainable investments account for more than a third of global assets," Reuters (July 19, 2021)
[9] The Global Sustainability Study 2021, conducted by Simon-Kucher & Partners on more than 10,000 people across generations and countries

Example agenda for the first roundtable discussion

Proposed agenda for collective discussion

Agenda item #1: Transition to ZEVs
This lever is inherently crucial for value creation and competitive differentiation for the industry and typically does not lend itself well to collaboration. However, some opportunities exist to facilitate demand of EVs and other low-emission vehicles. Example topics to discuss include:

1.1 Opportunities to proactively drive electric vehicle charger rollout (especially in developing countries)

1.2 Opportunities to increase education and transparency on purchasing decisions on lower-emission vehicles

1.3 ...

Agenda item #2: Fossil-free power provision for use phase
This topic is traditionally an area driven outside of the automobile community, by energy and utility companies. The question here is can OEMs play a greater role in enabling fossil-free power that will support adoption of zero emission vehicle sales and drive carbon reduction. Example topics to discuss include:

2.1 Opportunities to offer new value propositions that cover or influence use phase emissions (for example, bundle green power contract with electric sales, through utility agreements or offsets)

2.2 Opportunities to nudge consumer behavior in driving and real-time feedback (for example, dashboards and interfaces to drive systematic change in post-sale emissions)

2.3 Opportunities to nudge consumer charging behaviors (for example, partnership with charging app providers to prompt consumers to charge at low-intensity time periods)

2.4 ...

Agenda item #3: Reduce supply chain emissions
Arguably the most influenceable topic for OEMs, this area presents predominantly "under-the-skin" opportunities, both collective actions (listed below) and individual efforts (for example, design-for-carbon reduction/circularity, internal carbon pricing, and sustainability KPIs in performance management). Example topics to discuss include:

3.1 Opportunities to establish common standards, metrics, and criteria for, for example, LCA measurements, carbon intensity, ESG guidelines in sourcing requirements and supplier agreements, leveraging consortiums that increase cooperation among key players, and transparency across the value chain

3.2 Leverage strength as a consortium to send stronger market signals to suppliers, providing longer-term demand and support scaling of low-carbon alternatives. Further investments in strategic partnerships and co-investment with suppliers to accelerate carbon reduction in low-carbon production of battery, steel and iron, aluminum, and other materials

3.3 Opportunities to collaborate on end-of-life material management, recycling and reuse of batteries and other valuable vehicle componentry

3.4 ...

The path to a sustainable future lies ahead, and it is up to the industry to set the pace at which one shall travel it.

Methodology

1 Modeling principles

Our modeling approach follows three key principles:

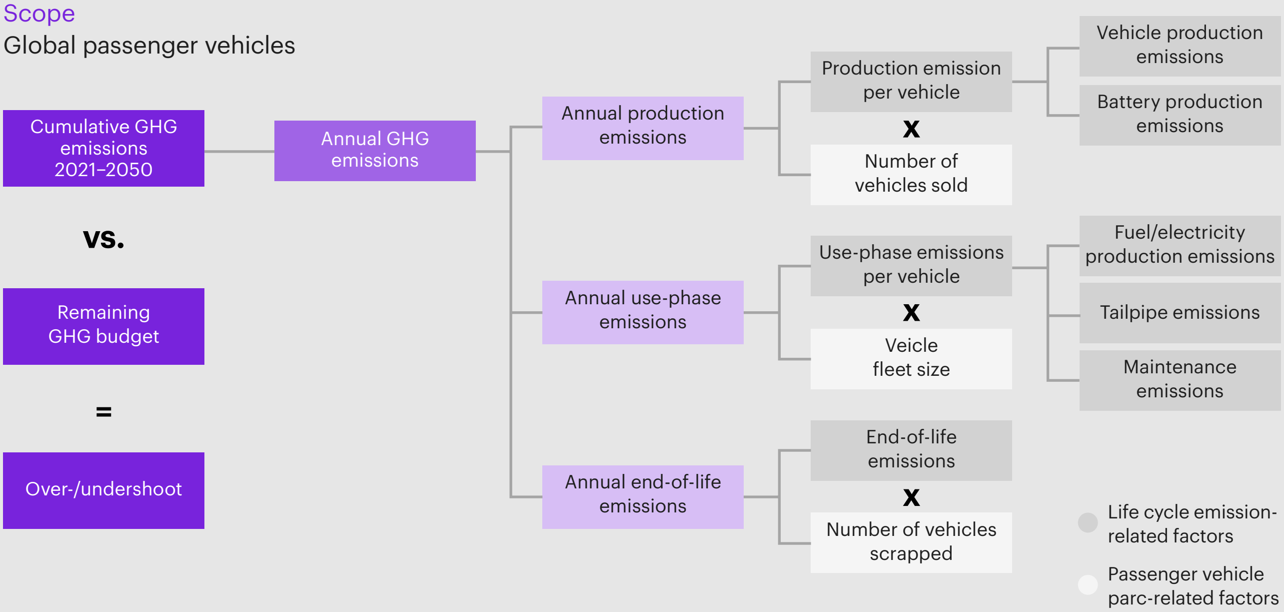
1. Build a strong fact base by using existing data and analyses from recognized sources such as IEA, ICCT, and IPCC
2. Showcase the full effect of emission reductions across three identified levers, not limited to the impacts from actions outlined in the main report
3. Minimize perception of over-pessimism by applying positive assumptions to prevent overestimation of carbon overshoot

2 Model structure

The model is built to estimate annual greenhouse gas emissions of the global passenger vehicle fleet from 2021 to 2050 and compare the cumulative amount to the remaining emission budget allocated to the passenger vehicle fleet for the same period (see figure 6). Two sets of factors (life cycle emission related and passenger vehicle parc related) are crucial inputs for the model.

Three distinct scenarios are created to assess the various degrees of gap between the 1.5-degree carbon budget for passenger vehicles and the cumulative emission after applying all three levers with different timelines. Sensitivity analyses have also been performed across key factors (see more in Sensitivity section).

Figure 6
The model estimates annual GHG emissions of the global passenger vehicle fleet and compares the cumulative amount to the remaining emission budget allocated



Note: GHG is greenhouse gas.
Source: Kearney analysis

2.1 Life cycle emissions

As outlined in the model driver tree, annual greenhouse gas (GHG) emissions are calculated by aggregating emissions in three main stages: production, use phase, and end-of-life. **Production emissions** represent vehicle and battery production emissions created by new cars sold in a specific year. **Use phase emissions** capture emissions from all vehicles in operation in that year, covering emissions related to fuel/electricity production, tailpipe, and maintenance. Lastly, **end-of-life emissions** occur when vehicles reach the end of lifetime and include recycling credits.[10]

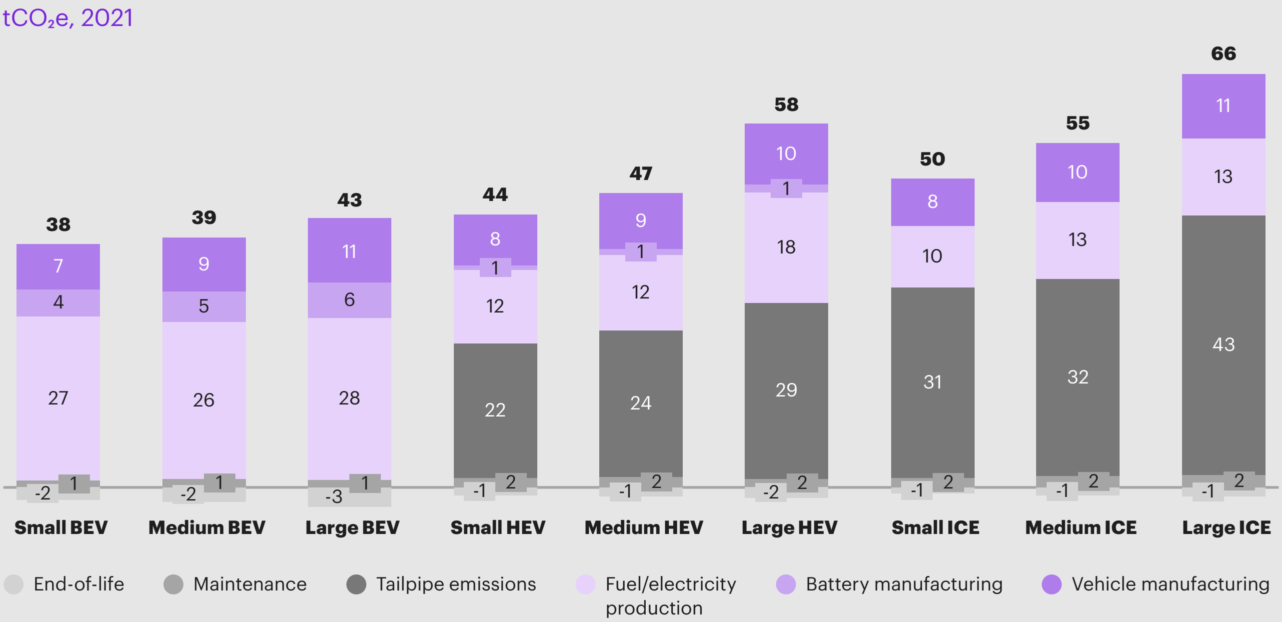
2.1.1 Estimation of 2021 life cycle emissions

The emissions related to the six stages of the life cycle have been determined from an LCA database, constructed by data collected on life cycle emissions across powertrain types, vehicle size segments, and geographies (see figure 7).[11]

It is assumed that production emissions occur at the year of sales, while use phase emissions are distributed over the lifespan of the vehicle.[12] In the model, fuel/electricity production and tailpipe emissions are assumed to be frontloaded in the beginning of the lifetime with fuel/electricity production and tailpipe emissions decreasing by about 3 to 4 percent annually.[13] This implies that fuel/electricity and tailpipe emissions are higher than average emissions the first half of the lifespan, while lower than average the last half of the lifespan (see figure 8 on page 11). The frontloading captures the effect of new cars being driven more than old cars (higher share of leased cars and taxis).[14]

[10] Included to ensure a positive projection of emission pathways.
[11] Total sample of 74 vehicles.
[12] The LCAs in the LCA database consider a life cycle of 16 years and total distance of 240,000 km. The use phase is therefore divided by 16 and distributed over the expected lifetime of the cars.
[13] ICCT estimates 5 percent annual mileage decrease. A decrease of fuel efficiency of 10 percent within 100,000 km is taken into consideration (Lim et al. (2018): Experimental Analysis of Calculation of Fuel Consumption Rate by On-Road Mileage in a 2.0 L Gasoline-Fueled Passenger Vehicle.
[14] A Dutch study shows average mileage of about 27,000 km for private and business leasing in 2020. Source: VNA: Vehicle leasing market in figures 2021.

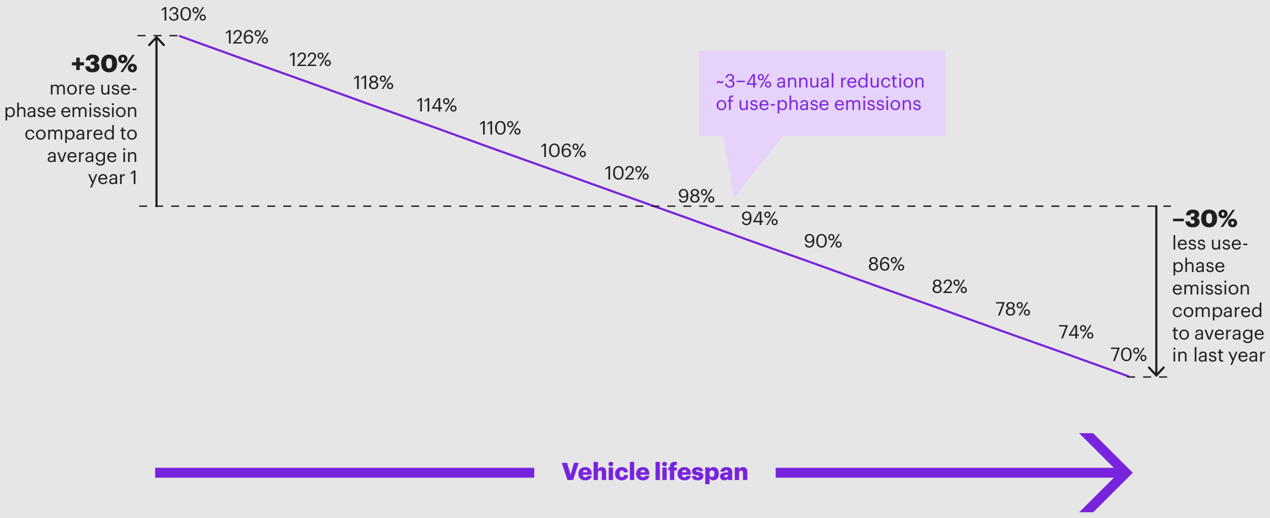
Figure 7
BEVs account for the lowest life cycle emissions by vehicle segment



Notes: BEV is battery electric vehicle. HEV is hybrid electric vehicle. ICE is internal combustion engine. Numbers may not resolve due to rounding.
Sources: triangulated from Green NCAP, ICCT, Polestar LCA, and Kearney analysis

Figure 8
Fuel/electricity and tailpipe emissions produce higher than average emissions the first half of the lifespan, but lower than average the last half

(% of average)



Source: Kearney analysis

2.1.2 Historic and future development of life cycle emissions
Life cycle emissions evolve over time, given potential improvements in production efficiency, fuel economy, and electricity mix. These improvement factors have been incorporated in the baseline model.

The median European factory in the automotive industry states 8 percent annual reduction of scope 1 and 2 emissions (four-year average), based on Kearney Factory of the Year benchmarking. Thus, a productivity improvement in battery and vehicle production emissions of about 1.5 percent year-on-year is assumed, given a realistic and easily achievable goal on the global level. This includes a steeper reduction of scope 1 and 2 emissions from OEM factories (which represents about 11 percent of total supply chain emissions) where electrification and shifting to fossil-free electricity is more easily accomplished. It is further assumed that the increase in energy density for batteries is offset by increased pack size to allow for longer ranges.[15]

For use-phase emissions, the carbon intensity of the electricity mix and assumed development of fuel economy is considered. Following the ICCT projection, a fuel economy improvement of about 10 percent by 2030 is assumed.[16] This improvement is extrapolated toward 2050, applying the same annual increase results in improved fuel economy of 28 percent, 31 percent, and 34 percent for HEV, ICE, and BEV respectively. Similarly, the same annual improvement is assumed prior to 2021 resulting in 18 to 27 percent increased fuel consumption for BEVs and ICEs respectively for vehicles sold in 2005. A direct correlation between fuel economy and the fuel/electricity production and tailpipe emissions is assumed for all vehicle segments (see figure 9 on page 12).

Electricity mix data is taken from IEA's Announced Pledges Scenario (APS), projecting the development in relative energy source usage based on current communicated pledges globally. The APS assumes 76 percent fossil-free energy by 2050 and is the most optimistic IEA scenario.[17]

[15] ICCT estimates that increased pack size will lead to larger increase in emissions relative to benefits from energy density. ICCT (2018): Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions.
[16] ICCT (2021): A global comparison of life cycle greenhouse gas emissions of combustion engine and electric passenger cars.
[17] Includes wind, solar PV, hydro, nuclear, and other low-carbon sources (includes biofuel).

Figure 9
The carbon intensity of the electricity mix and assumed development of fuel economy is considered for use-phase emissions

Powertrain	Fuel economy 2005 (2021 index)	Fuel economy 2050 (2021 index)
BEV	124	66
HEV	118	72
ICE	127	69

Notes: BEV is battery electric vehicle.
HEV is hybrid electric vehicle.
ICE is internal combustion engine.
Source: Kearney analysis

A direct correlation is assumed for reduced carbon intensity of the electricity mix and reduction in emissions connected to fuel/electricity production for BEVs. For ICEs and HEVs the correlation is assumed to be 0.2 and 0.4 respectively (accounting for potential future electrification of gasoline and diesel production). With these assumptions, a 20 percent reduction of carbon intensity of the power mix between 2021 and 2030 will result in 20 percent emission reduction of the fuel/electricity production stage for BEVs, 4 percent reduction for ICEs, and 8 percent reduction for HEVs bought in the same year.

2.2 Global passenger vehicles

Besides life cycle emission-related factors listed above, data collection and assumptions were made for vehicle fleet, vehicle sales, and lifetime by powertrain type.

2.2.1 Global passenger vehicle fleet

The model constructs the global passenger vehicle fleet using data on fleet size from IHS between years 2000 and 2031. Beyond 2031, the car parc is assumed to develop based on average historical growth rates, adjusted downward in a flattening trend. The car parc is split into powertrain categories (BEV, HEV, ICE) and size categories (small, medium, large) based on the collected data.

Looking at the development of the car parc, the average lifetime of cars becomes an impactful variable as it affects the yearly rate by which the car parc is reduced due to scrapping if no new cars are sold. The model assumes average lifetimes of 16, 18, and 18 years for BEVs, HEVs, and ICEs respectively.[18] BEVs are assumed to have shorter lifetimes than HEVs and ICEs due to uncertainty around battery lifetime with most producers expecting a lifetime of 17 to 18 years while the model is deliberately more conservative. Vehicle lifetimes are assumed constant for the period 2000 to 2050. Given the lifetimes, the number of BEVs sold in a specific year will consequently be scrapped 16 years later, and HEVs/ICEs 18 years later, comprising the number of vehicles scrapped going forward (see figure 10).

2.2.2 Global passenger vehicle sales

Historically, global passenger vehicle sales volumes are estimated using sales data from IHS. Going forward, vehicle sales volumes are estimated from the sum of change in vehicle fleet and the number of vehicles scrapped, keeping the annual growth of the car fleet fixed to IHS data and holding vehicle lifetimes stable.

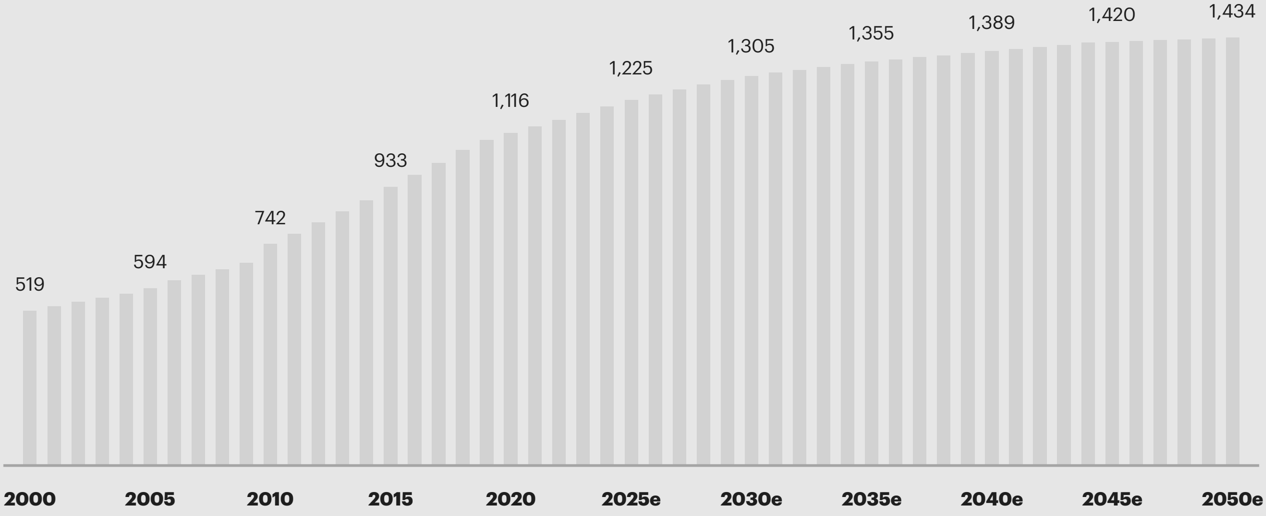
Vehicle sales mix (powertrain and size) is based on a triangulation of various datasets. Vehicle powertrain mix is linearly interpolated from historical data in 2021 to the ICCT progressing scenario for 2030, 2040, and 2050. Vehicle size mix is assumed to follow projections in data from LMC and Marklines, and thereafter kept constant from 2034.

[18] ICCT (A global comparison of life cycle greenhouse gas emissions of combustion engine and electric passenger cars) and Kearney research.

Figure 10

The global car parc is assumed to develop based on average historical growth rates, adjusted downward in a flattening trend

Baseline (million units; 2000–2050)



Sources: HIS; Kearney analysis

2.3 Estimated GHG budget for global passenger vehicles

The total global remaining GHG budget to stay within the 1.5-degree pathway is estimated at 500 $GtCO_2$ from 2021.[19] The budget allocation for automotive and the passenger vehicle segment within will certainly be discussed, and there are arguments to both increase and decrease the share of total budget allocated to the automotive industry. On one hand, if the goal is to collectively ensure staying within the 1.5-degree budget (and all agree this is a tremendous challenge), the industries with a more tangible and clearer pathway should get a smaller part of the budget.

The opposite has also been argued, that industries such as automotive have invested more in R&D to reduce emissions, thus creating a clear pathway, and should therefore get a larger share of the global budget.

In this report, a budget proportional to current share of global emissions is allocated the passenger vehicle fleet, and hence it is assumed that each industry needs to reduce emissions at equal pace. The model estimates 5.5 $GtCO_2e$ emissions in 2021, representing 15 percent of the reported global emissions of 36 Gt.[20] Furthermore, IEA estimates total tailpipe emissions from road transport at 3.2 $GtCO_2e$, which suggests about 9 percent of emissions currently come from passenger car tailpipe and represents a reasonable share of the 15 percent lifetime emission.[21] By allocating budget based on the model output, the sensitivity toward assumptions in the modeling is reduced. For example, if the size of the passenger vehicle fleet is doubled, the budget allocated to the passenger vehicles would also double, and hence the conclusions of this report would remain unchanged.

2.4 Emission projection baseline

The baseline scenario underlines the urgency and the challenge the automotive industry is facing. The baseline trajectory for the passenger vehicle industry will result in an overshoot of 75 percent compared to the 1.5-degree target by 2050. In fact, inaction would mean losing 7 percent of the carbon emissions budget each year, resulting in 50 percent lost before 2027, and the full budget being spent by 2035 (see figure 11 on page 15).

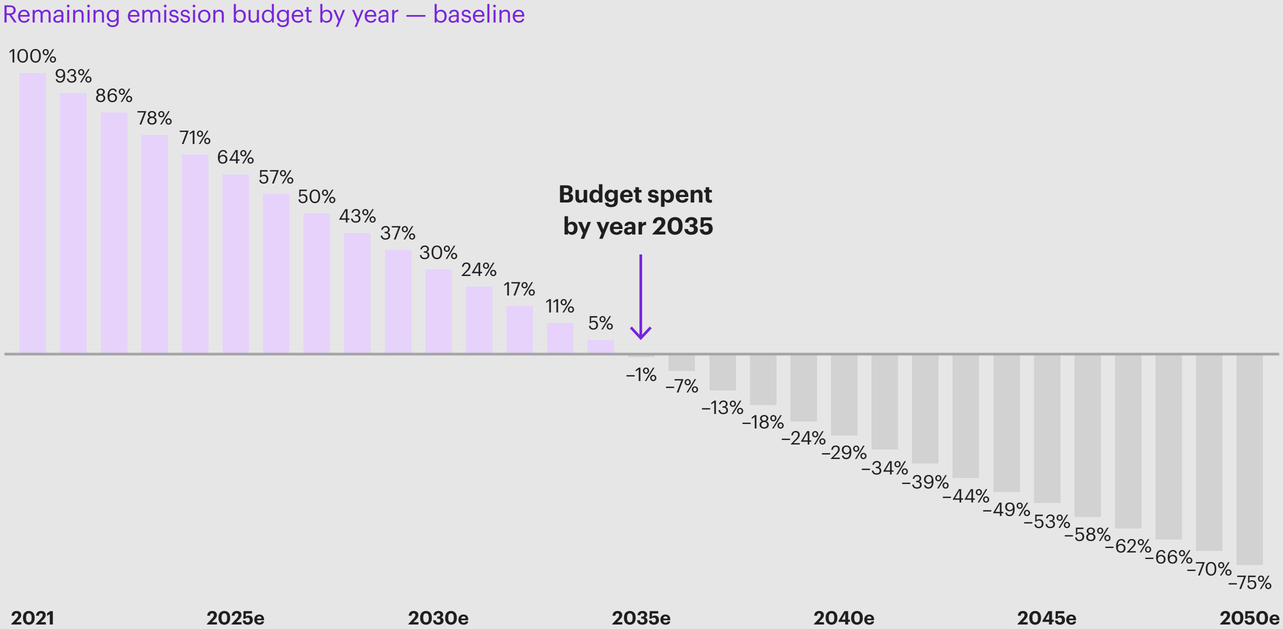
Over time, yearly emissions in the baseline will be reduced by 43 percent in 2050 compared to the 2021 level mainly from increased adoption of BEVs, supply chain efficiencies, and improved electricity mix. As BEVs' share of the vehicle fleet increases (reaches 42 percent of vehicle fleet in 2050), use-phase emissions will be reduced. However, short term the switch to BEVs increases emissions as production emissions (mainly battery production-driven) are larger for BEVs compared to HEVs and ICEs. In sum, the use-phase emission reductions more than offset the increased production emissions (see figure 12 on page 15).

The baseline scenario underlines the urgency and the challenge the automotive industry is facing.

[19] IEA: World Energy Outlook 2021 (World Energy Outlook 2021 (windows.net)) based on IPCC 50 percent likelihood scenario
[20] IEA: World Energy Outlook 2021 (World Energy Outlook 2021 (windows.net)) based on IPCC 50 percent likelihood scenario
[21] IEA: Technology perspectives 2020 (Technology needs in long-distance transport – Energy Technology Perspectives 2020 – Analysis - IEA)

Figure 11

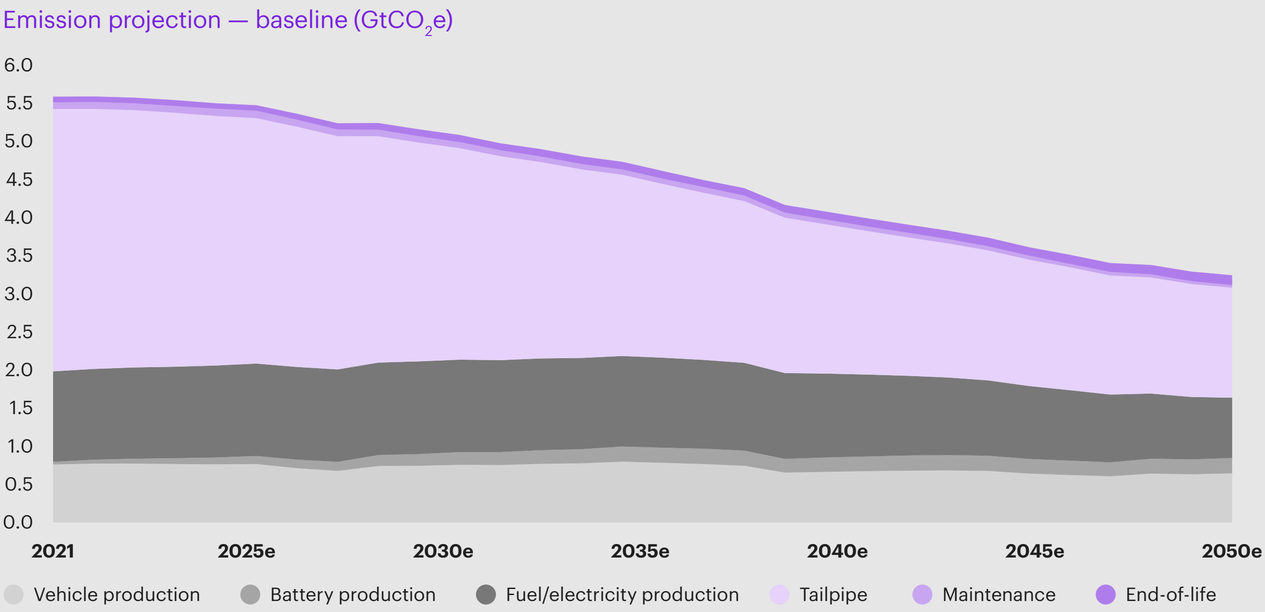
Inaction would result in the loss of 7 percent of the carbon emissions budget each year, with the full budget being spent by 2035



Source: Kearney analysis

Figure 12

The use-phase emission reductions resulting from increased adoption of BEVs will more than offset the increased production emissions



Note: BEV is battery electric vehicle.

Source: Kearney analysis

3 Sensitivity analysis

A pragmatic approach is taken to build the emission pathway model. The model therefore includes assumptions, where complete data was not available, that impact the baseline emission trajectory with varying degree. A sensitivity analysis is conducted to understand how the model is affected by assumption changes. An extensive list of assumptions and sensitivities in the baseline model is found in figure 13 on page 17. In this section, two assumptions with high sensitivity are outlined.

Vehicle lifetime. In the model, an average lifetime of 18 years is assumed for HEV and ICE, while for BEV this is set to 16 years. In this analysis it is assumed that the battery lifetime is the bottleneck for the lifetime of BEVs. Kearney analysis shows a large variety in battery lifetime by battery technology and vehicle model. On average, the state of health (SOH) of the batteries is reduced 10 to 15 percent by year 7.[22] The trend is positive, with average expected lifetime increasing toward +15 years, and OEMs claiming that battery lifetime of new cars is exceeding 240,000 km.

The model has limited sensitivity toward the lifetime of BEVs and HEVs, while the expected lifetime of ICE vehicles has great influence on the absolute value of emissions in the baseline trajectory. Increased lifetime of ICE implies a deceleration of the vehicle fleet electrification and thereby increased emissions from the use phase of ICE. The relative overshoot of emissions will, on the other hand, fall as the model will simulate a larger vehicle fleet and thereby budget allocated to the passenger vehicle fleet (see figure 14 on page 18).

Fuel economy development. The model output has high sensitivity toward fuel economy because the assumption will impact the budget and projected emissions in opposite directions. A steeper increase in fuel economy development will imply greater emissions in year 1, and hence a *larger* budget for the passenger vehicle fleet. The steep increase in fuel economy will also have a positive effect on the use-phase emissions of future cars.

In the model, the future fuel economy projection of 1.1 to 1.5 percent is based on ICCT projection for 2030, and it is assumed that the year-over-year improvement will continue to 2050.[23] This paints a positive picture of the future. A more likely scenario is that fuel economy improvement will stall.[24] Furthermore, according to IEA, almost 40 percent of fuel economy improvements have been eroded by increased weight and power following the trend of increased SUVs in sales (see figure 15 on page 18).

Almost 40 percent of fuel economy improvements have been eroded by increased weight and power following the trend of increased SUVs.

[22] Source: Geotab (>6,000 cars) and Kearney analysis with annual mileage of 15,000 km.
[23] Dependent on powertrain. 1.1% for HEV, 1.4% for ICE, and 1.5% for BEV.
[24] IEA: Global fuel economy institute 2021 (Global Fuel Economy Initiative (windows.net))

Figure 13

There are many assumptions and sensitivities in the baseline model

	Assumption input			Cumulative emissions ($GtCO_2e$)		Overshoot (% of budget)		
Topic	**Current**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Comment**
BEV lifetime	16	12	20	135.8	132.4	77.4	72.9	Minimal impact on budget
HEV lifetime	18	14	22	133.3	133.9	74.4	74.8	Minimal impact on budget
ICE lifetime	18	14	22	111.9	155.3	78.6	72.6	Lifetime of ICE has large impact on budget as emissions in 2021 will increase (larger car fleet). Impact on overshoot is limited.
Frontloading	25%	0%	50%	135.6	132.3	78.2	72.2	Frontloading will increase emissions in 2021 (increase budget) and reduce emissions toward 2050 as increase in share of BEV mileage will be steeper (transition to BEV).
LCA	Database	Lowest per segment	Highest per segment	97.1	190.8	70.6	70.7	The LCA will impact the entire trajectory from 2021 and 2050 and thereby impacts the budget. High sensitivity in absolute terms but limited in terms of overshoot.
Annual fuel economy improvement	1–1.5%	0%	2%	140	130	63.2	99.1	Double sensitivity as the budget increases with increased annual increase (historical improvement is assumed to be the same, hence old cars will emit a lot).
Electricity mix development	IEA APS	IEA STEPS	IEA Net-Zero	136.3	128	78.0	67.3	Improvement of electricity grid impacts the use phase of both new and old cars (greatest impact on BEVs).
Use-phase emission correlation with electricity mix 1. ICE 2. HEV	1. 0.2 2. 0.4	1. 0.1 2. 0.2	1. 0.3 2. 0.5	134.7	132.9	75.9	73.6	Limited impact on emissions. Current assumption of 20% correlation with fuel production with electricity mix is a positive assumption.
Vehicle mix	Progre-ssive	ICCT baseline	N/A	141.7	N/A	85.1	N/A	ICCT baseline considers current policies, and only 29% BEV sales in 2050.
Vehicle fleet development	IHS Markit fleet projection	N/A	Wood Mackenzie projection	N/A	150	N/A	96.0	Wood Mackenzie estimates annual growth of 1.5–2% until 2050.
Annual production productivity improvement 1. Scope 1 and 2 2. Scope 3	1. 4.1% 2. 1%	1. 0% 2. 0%	1. 4.1% 2. 2%	138.2	131.1	80.5	71.2	Budget is not impacted by the assumption. Hence, the reduction in annual emissions will have direct impact on projected supply chain emissions.

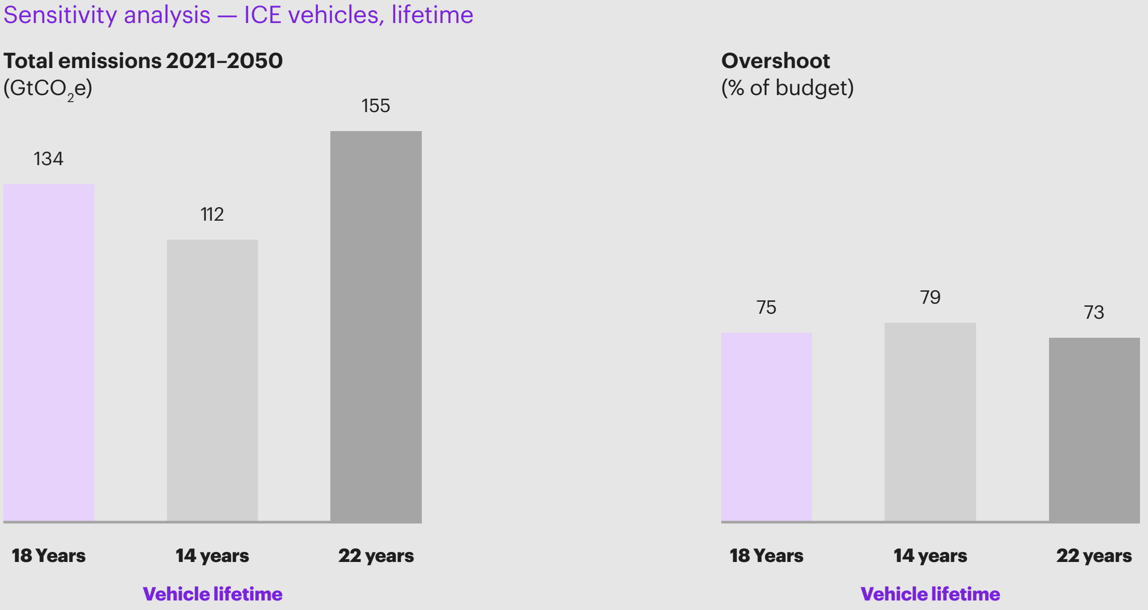
[1] As a proxy: scope 2 emissions only amount to about 10 percent of scope 1 and 2 emissions reported by Shell, meaning that the majority of energy consumption in fuel production comes from direct sources.

Notes: BEV is battery electric vehicle. HEV is hybrid electric vehicle. ICE is internal combustion engine. LCA is life cycle assessment. IEA is International Energy Agency. ICCT is international Council on Clean Transportation.

Sources: Shell sustainability report 2021; Kearney analysis

Figure 14

The expected lifetime of ICE vehicles has substantial influence on the absolute value of emissions in the baseline trajectory

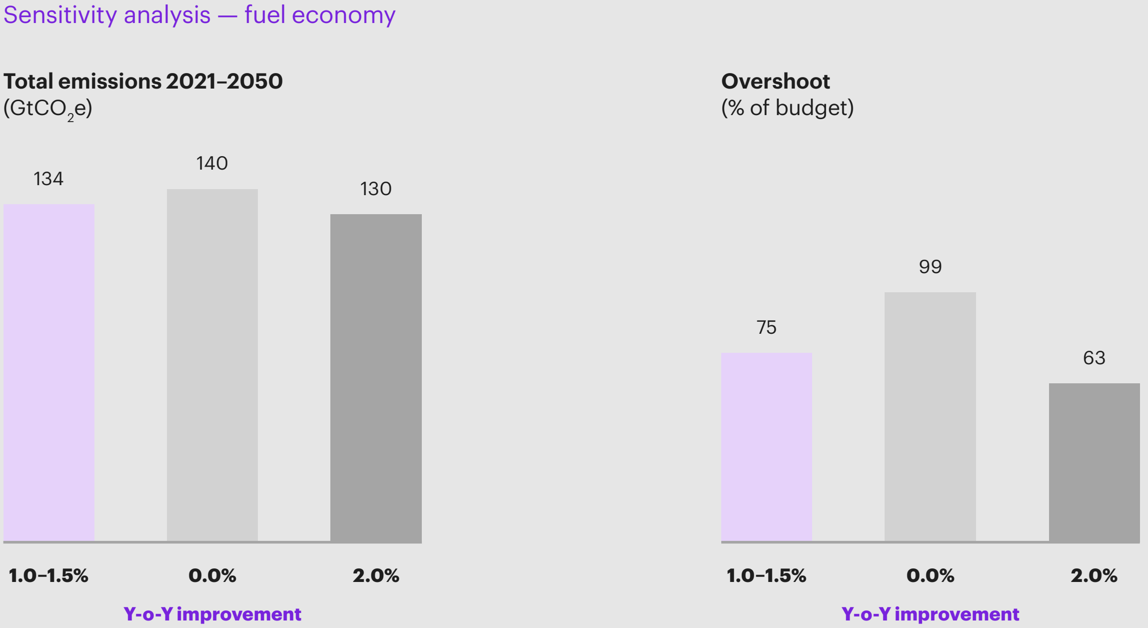


Note: ICE is internal combustion engine.

Source: Kearney analysis

Figure 15

The most likely scenario is that fuel economy improvement will stall



Source: Kearney analysis

4 Impact from levers

4.1 Lever 1 – Transition to ZEVs

To reduce carbon emissions in the passenger car industry, the most significant impact will come from reducing the use-phase emissions of ICE vehicles, which generate 80 to 85 percent of their life cycle emissions in the use phase, of which 60 to 65 percent is tailpipe emissions. Although transitioning to BEVs would mean higher production-related emissions, mainly from battery production, it is a net benefit from a life cycle emissions standpoint as the BEVs unlock potential in a carbon-free use phase.

However, a challenge in need of a solution is the speed of the transition to BEV. Inspiration can be taken from several sources including best practice countries, ambitious regional policies, and progressive reports. This lever aims to emulate the emissions reduction if the speed can be derived from various outlooks, transitioning into 100 percent BEV at different periods in time. All scenarios outlined under lever 1 assume seamless rollout of infrastructure to support growth in BEVs.

4.1.1 Impact of lever 1 improvements

The transition to BEVs impacts the aggregated life cycle emissions directly by reducing the use-phase emissions compared to ICEs and HEVs. Thereby, the carbon intensity of the global vehicle fleet would be reduced over time as the fleet gets increasingly tinged by BEVs. However, in the short term, emissions will increase due to BEVs having higher production emissions. This effect is smoothened and inverted over time as the vehicles move into their use phase where BEV emissions are low or close to zero (powered by 100 percent fossil-free electricity).

4.2 Lever 2 – Fossil-free energy

In reducing the emissions of the passenger car industry, transitioning into BEVs is only the first step of the value chain decarbonization. Powering the BEVs on the roads with fossil-free energy is a natural extension to completely remove any use-phase emissions from the global vehicle fleet. Fossil-free energy sources (wind, solar, hydro, nuclear, other fossil-free) currently contribute to 39 percent of the global electricity mix, exposing both substantial progress and future improvement potential.[25]

Aiming to utilize the future improvement potential, this lever bases the future electricity mix on outlooks from research institutes, adjusted for a faster transition to fully fossil-free energy. Targeting efficiency improvements and reduced waste in the electricity grid, the lever also assumes declining carbon intensities of power sources compared to the baseline.

4.2.1 Impact of lever 2 improvements

The transition to fully fossil-free energy drives positive environmental impact by reducing the annual fuel/electricity production emissions compared to the 2021 baseline. In relative terms, the emissions related to electricity production decline faster than for fuels. Therefore, the transition to fossil-free energy removes most of the use-phase emissions of BEVs while only reducing a small share of use-phase emissions from ICEs and HEVs.

4.3 Lever 3 – Reduce supply chain emissions

For the third lever, the emission reduction potential of the supply chain emissions is evaluated. For all supply chain emissions there are three ways to reduce emissions: 1) reduce carbon intensity of materials and processes in the production phase, 2) change design to reduce the amount of carbon-intensive material in the vehicle, or 3) increase circularity and recycling.

The focus of the analysis is to determine the emission reduction potential in point 1 above for the four largest emission contributors: steel, aluminum, battery, and manufacturing (78 percent and 73 percent of supply chain emissions for BEV and ICE respectively). The emission reduction is to a large extent connected to electrification, and out-phasing of fossil fuel (mainly coal and natural gas) with hydrogen and ensuring power supply from fossil-free power sources.

Even if the reduction potential is focused on the emission intensity of the production, there are other means the OEMs can use to reduce emissions (for example, by improving design, ensuring a functioning reverse supply chain, and increasing use of recycled materials).

Steel

Today, the steel industry relies heavily on coal, which supplies 74 percent of the energy input in production.[26] Coal is used in the reduction process of iron ore in a blast furnace. In 2019, 70 percent of crude steel was produced with blast furnaces, mainly driven by Chinese steel production representing 53 percent of global production.[27]

[25] IEA (2021): World Energy Outlook 2021 (windows.net)
[26] IEA (Iron and Steel Technology Roadmap - Towards more sustainable steelmaking (windows.net))
[27] World Steel Association: World steel in figures 2022

Low-carbon steel is achieved by utilizing green hydrogen in the direct reduced iron (DRI) process, replacing fossil fuel combustion in the blast furnace (mainly coal) or DRI process (mainly natural gas). By ensuring that the electric arc furnace (EAF) is powered by fossil-free electricity sources, about 90 percent of emissions from steel production will be eliminated. WEF defines low-emission production of steel to have 95 percent reduced emission, supplementing the DRI-EAF process (green hydrogen and fully fossil-free energy) with carbon capture and storage (CSS).[28]

Aluminum

Consumption of electricity contributes to 70 percent of the aluminum industry's emissions, of which the majority is consumed during electrolysis of alumina.[29,30] Shifting to fossil-free energy is therefore the most important lever to pull to reduce the energy intensity of primary aluminum production. About 55 percent of the aluminum industry's electricity consumption is self-generated, where coal is the main power source in China and the rest of Asia, contributing 65 percent of global primary aluminum production.[31] The electricity mix used for powering the alumina industry has therefore a higher GHG intensity than the global electricity mix. WEF defines low-emission primary aluminum production to have a 90 percent emission reduction compared to current levels.

The International Aluminum Institute estimates a reduction of 95 percent in aluminum production by 2050 is needed to stay within the 1.5-degree pathway for the industry, enabled by increasing share of recycled aluminum by 155 percent from 2018 to 2050 and reducing carbon intensity from primary aluminum by 97 percent compared to 2018 values.[32]

Manufacturing/assembly

Approximately 35 percent of vehicle manufacturing and assembly emissions comes from electricity consumption. The remaining emissions is from fossil fuel, mainly natural gas.[33,34] Increased electrification is assumed feasible, especially for heating purposes, contributing to about 50 to 60 percent of fossil fuel in manufacturing.[35] Full electrification of heating combined with electricity from fossil-free sources results in a GHG reduction potential of about 70 to 75 percent.

Battery

The share of emissions coming from upstream material production ranges between 20 and 30 percent dependent on electricity mix and fuel use.[36,37] Approximately 30 percent of emissions during battery cell production and pack assembly comes from electricity consumption.[38] Full electrification of battery cell production and pack assembly is a viable option to remove gas consumption in areas with a less carbon-intensive electricity grid. Assuming full adoption of fossil-free energy sources, a reduction of GHG emissions of about 98 percent is achievable.

About 50 percent of energy use in upstream material production comes from electricity consumption.[39] Assuming a global electricity mix and equal share of coal and gas as combustion fuels this results in about 50 percent of emissions related to electricity consumption. Assuming adoption of fossil-free energy sources to generate the electricity, a potential emission reduction of about 49 percent is achievable for material production.

Combining the potential for cell and pack assembly and material production an emission reduction potential of about 58 percent is achievable.

In addition to reduction of energy intensity per material and production processes, an additional 25 percent emission reduction can be achieved from battery reuse and material recycling.[40] Alternative materials and increasing energy density to reduce total pack mass are some other ways to reduce further emission impact and are included as part of the long list of action examples in the next section.

4.3.1 Impact of lever 3 improvements

In a scenario with 100 percent BEVs in the vehicle fleet charged with fossil-free power, the emissions created in the supply chain will still limit the passenger vehicle fleet to reach net zero. The improvement of supply chain emissions is added to all vehicle types in the model. Supply chain emissions are greater for BEVs than for HEVs and ICEs and the reduction of supply chain emissions will, therefore, have greater impact of total emissions in a scenario with increased share of BEVs in the vehicle fleet.

[28] WEF Net Zero Tracker (WEF_NetZero_Industry_Tracker_2022_Edition.pdf (weforum.org))
[29] IEA (Aluminium – Analysis - IEA)
[30] Nunez, et.al. (2016): Cradle to gate: Life cycle impact of primary aluminium production.
[31] International Aluminium (Primary Aluminium Production - International Aluminium Institute (international-aluminium.org))
[32] International Aluminium (1.5 Degrees Scenario: A Model To Drive Emissions Reduction - International Aluminium Institute (international-aluminium.org))
[33] Sato, et.al. (2020): Energy consumption analysis for vehicle production through a material flow approach. doi:10.3390/en13092396
[34] Argonne (2010): Energy consumption and carbon emission analysis of vehicle and component manufacturing.
[35] Argonne (2010): Energy consumption and carbon emission analysis of vehicle and component manufacturing.
[36] Dai, et.al (2019): Life cycle analysis of lithium-ion batteries for automotive applications
[37] Transport and environment (2020): How clean are electric cars?
[38] Transport and environment (2020): How clean are electric cars?
[39] Argonne (2010): Energy consumption and carbon emission analysis of vehicle and component manufacturing.
[40] ICCT (2018): Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions.

5 Long list of action examples

The primary purpose of our report—summarized in the shorter executive summary—is to explore opportunities for the industry to consider further action to tackle the challenge we face. In the short report we highlight several actions under the three themes we believe merit a coordinated discussion. Nonetheless, during the process we develop a longer list of action examples across all levers to reduce carbon emission. The list below is by no means exhaustive but serves as an inspiration for OEMs to take individual and collection action (see figure 16).

Figure 16
There are a number of action examples across all levers that can lead to reduced carbon emission

Lever	Action	Examples
1. Transition to ZEVs	Accelerate portfolio electrification and increase EV production capacity	— Use advanced analytics to fast-track strategic and operational road map, and optimize portfolio planning process. — Increase knowledge sharing on best practices and key learnings across the entire organization and among industry peers. — ...
	Take ownership and drive EV rollout	— Partner with EV infrastructure providers or create joint venture to promote mobility solutions, especially in developing countries. — Invest in own infrastructure and expand into adjacent segment on the value chain to create competitive edge. — Include carbon intensity as an integral part of customer conversations. — Include sales incentives for low-carbon product sales. — ...
	Increase awareness	— Increase education and transparency on purchasing decisions on lower-emission vehicles. — Reprioritize marketing spend to deepen consumer knowledge on EV environmental benefits. — ...
2. Renewable energy in use phase	Change charging electricity mix	— Explore new value proposition such as bundling green power contract with EV sales or offset environmental impact. — Partner with relevant utility companies to drive renewable energy through utility agreements. — Invest in renewable energy production. — ...
	Optimize charging and use phase behaviors	— Invest in or partner up with providers in software and dashboard to visualize and integrate sustainability-related data for end users. — Invest in or partner up with providers in EV charging apps to optimize charging at low-intensity time periods. — Collaborate to drive more standardization in charging networks and charging apps. — Incentivize sharing of charging locations in both residential and public networks. — Support or finance at-home EV charging through home solar panels. — ...
Related	Reduce charging infrastructure emission	— Partner with charging station manufacturers to increase sustainable material use and share relevant materials. — Collaborate and create an aftermarket for private and commercial charging stations. — Invest in or partner up with relevant players in new EV charging technologies with better efficiency and reduced charging losses. — Collaborate and share latest innovations in designs. — ...

Lever	Action	Examples
3. Reduce supply chain emissions	Support scaling of low-carbon virgin material and battery production	— Include environmental impact, carbon intensity, ESG guidelines, and so on as key criteria in RFP and sourcing decisions for all components and materials. — Enter strategic collaboration with supplier or invest in low-carbon alternatives to accelerate R&D and innovation. — Invest in strategic partnerships and co-invest with suppliers to accelerate carbon reduction in low-carbon production of battery, steel and iron, aluminum, and other materials. — Define industry standards (for example, LCA measurements) and common climate criteria to refine sourcing requirement. — ...
	Reduce consumption and increase recycling	— Collaborate on end-of-life material management, recycling, and reuse of batteries and other valuable vehicle componentry. — Optimize design for decarbonization (for example, increase material utilization, lower material amount/reduce total battery pack mass). — Incorporate design for circularity in own vehicle design and battery design (for example, more recycled materials), manufacturing, and supply chain. — Actively investigate part reduction and efficient integration of features. — Invest in mono material assembly development for improved end-of-life recycling. — Investigate right-sizing of battery for real range required by customers. — Continue to investigate opportunities to lighten the vehicle body mass. — Utilize prescriptive and analytical tools to systematically guide early design stage and assess environmental impact. — Utilize digital tools and technologies (for example, digital twins, 3D printing) for better prototyping. — ...
	Reduce in-house manufacturing emissions	— Use on-site power generation for electrification of manufacturing. — Switch from gas oven to electric oven. — Continue optimizing systems (for example, HVAC, heating) to improve energy efficiency and reduce waste and leakage. — Continue improving production and equipment efficiency through, for example, investing in automation and streamlining. — Eliminate spot orders through better demand forecasting and ordering process. — Eliminate high-carbon transportation mode (for example, air freight). — Focus on DfM to minimize processes and improve efficiency. — ...
	Carbon-based decision-making and operations	— Create transparency and traceability of components and services across the entire supply chain by using software, solutions, and consortium such as Catena-X to create. — Integrate sustainability KPIs in performance management across ranks and positions. — Explore using internal carbon pricing to guide business decisions and operations. — Embed carbon intensity in supplier scorecards. — Strengthen governance on supplier performance and compliance to carbon intensity reduction. — Set emission reduction targets and plans in SRM (supply relationship management). — Consider including carbon impact in capex budget planning. — Explore potential green financing options (for example, loans, bonds) to accelerate execution of transition. — Create separate budget to drive green projects. — Increase awareness of sustainability elements in day-to-day activities. — ...
Other	Invest in future transportation mode	— Invest in mobility-as-a-service (car-sharing, ride-sharing) and key enablers such as autonomous driving technology. — Change business model from maximizing number of cars produced to maximizing utilization of cars already on the road through, for example, monetizing software and services, subscription models. — ...
	Improve lifespan of cars	— Continue investment in product quality and reliability improvement. — Extend product warranty. — Partner with preventative maintenance players. — ...

Notes: ZEV is zero emission vehicle. EV is electric vehicle. ESG is environmental, social, and governance. LCA is life cycle assessment. HVAC is heating, ventilation, and air conditioning. DfM is design for manufacturing. KPI is key performance indicator.

Source: Kearney analysis

6 Scenarios

6.1 Scenario 1

Combined emissions impact
Together, all levers and their most aggressive scenario expose the potential to break even with the Paris Agreement's 1.5-degree target. However, the scenario also underlines the criticality of pulling all levers simultaneously and fiercely. Only transitioning to 100 percent BEVs does not reduce emissions enough, overshooting by 50.5 percent, even if achieved as early as 2032. While requiring serious effort, complementing a full BEV adoption globally with a full switch to fossil-free electricity in the use phase by 2033 will also prove unsuccessful in complying with the Paris Agreement, overshooting by 25.4 percent (see figure 17). Ultimately, the two previously mentioned levers must be accompanied with 81 percent reduction in supply chain emissions by 2032 to stay within the allocated emissions budget for the passenger vehicles industry.

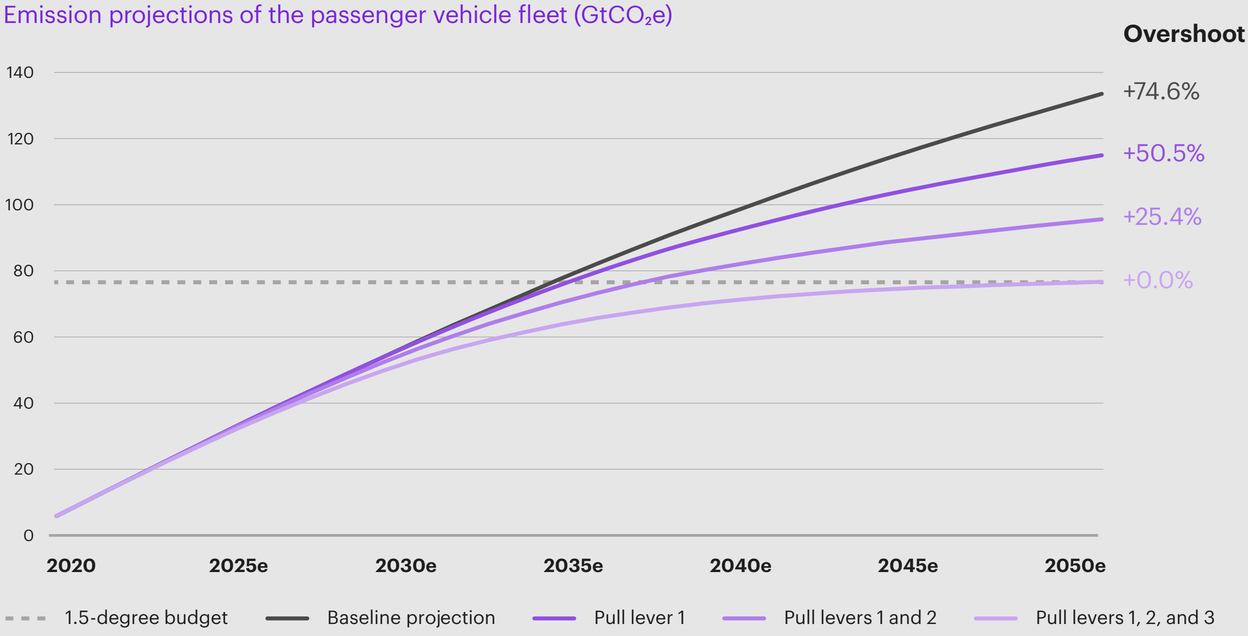
Lever 1 – Transition to ZEV. Fundamentally, the lever builds on the same data and assumptions as the baseline for the period 2000 to 2023. Constructing an ambitious BEV adoption trajectory, inspiration is taken from best practice countries Norway and the Netherlands (63.9 percent and 20.1 percent BEV sales respectively in 2021), as these countries have successfully adopted BEVs from comparable levels to today's global average of 5.7 percent BEV sales (5.6 percent in Norway in 2013, 5.5 percent in the Netherlands in 2018).[41]

Following the trajectory of best practice countries, 100 percent BEV sales would be achieved globally by 2032.

Lever 2 – Fossil-free energy. Fast-tracked IEA Net Zero Emissions builds on IEA's Net Zero Emissions Scenario, although adjusting 100 percent fossil-free (solar, wind, hydro, nuclear, other) energy use in the use-phase forward to start 2033, with linear interpolation between 2023 and 2033. Electricity mix shares within fossil-free and fossil are assumed to stay constant at 2021 level. Relative shares between fossil-free and fossil sources are assumed to remain constant after 2033.

[41] IEA.

Figure 17
In scenario 1, all levers and their most aggressive scenario have the potential to break even with the Paris Agreement's 1.5-degree target
Emission projections of the passenger vehicle fleet ($GtCO_2e$)



Source: Kearney analysis

Lever 3 – Reduce supply chain emissions. Considers the definition of low-emission production of steel and aluminum by WEF's Net-Zero industry tracker, and aggressive electrification of material production and manufacturing in the short term. Assumes 95 percent GHG emission reduction is achieved in steel production by 2032, 90 percent of emission reduction of aluminum production by 2032, 58 percent reduction of production intensity for batteries, 25 percent reduction of battery emissions from reuse and recycling by 2032, and 75 percent reduction of manufacturing emissions by 2032. It is assumed that the rest of supply chain emissions (not covered in the deep dive) is reduced by an average of the above.

6.2 Scenario 2

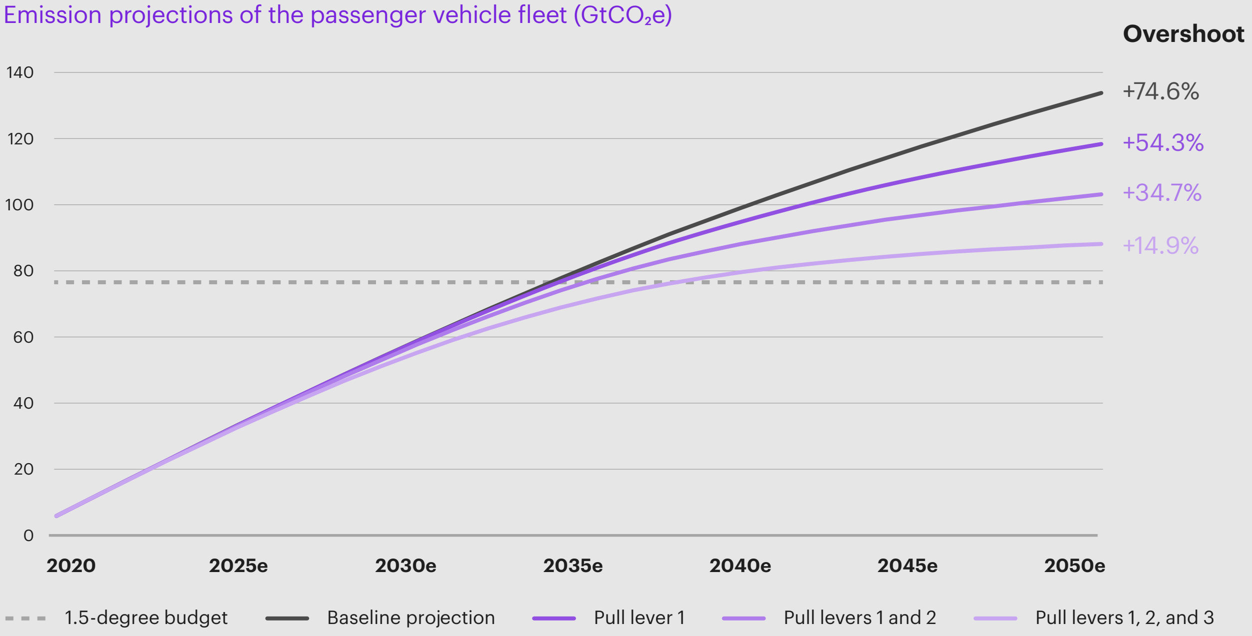
Combined emissions impact
Together, all levers and their second most aggressive scenario expose the severe impact that small deviations have when transitioning to compliance with the Paris Agreement's 1.5-degree target. By being marginally less optimistic in the adoption of BEVs, transition to fossil-free energy, and reduction of supply chain emissions, the model estimates an overshoot of 14.9 percent. Nonetheless, scenario 2 still highlights that by pulling all three levers semi-aggressively, the overshoot can be reduced from 74.6 percent to 14.9 percent (see figure 18).

Lever 1 – Transition to ZEV. Looking at the current most aggressive policies, the EU has introduced legislation banning sales of ICE vehicles by 2035.[42] Assuming global policy would follow suit, all vehicles sold post 2035 globally would be BEV.

Lever 2 – Fossil-free energy. Scenario 2, Accelerated IEA Net Zero Emissions, builds on IEA's Net Zero Emissions scenario, although adjusting 100 percent fossil-free energy use in the use phase forward to 2040, with linear interpolation between 2023 and 2040. Relative shares assumed to remain constant after 2040.

[42] European council, 2022, Fit for 55 - The EU's plan for a green transition - Consilium (europa.eu)

Figure 18
In scenario 2, which is marginally less optimistic, the best case is an overshoot of 14.9%



Source: Kearney analysis

Lever 3 – Reduce supply chain emissions. Considers switching current electricity consumption to fossil-free energy, either by global mix improvement or self-generation of fossil-free electricity. For steel, it is still assumed moving over to DRI-EAF. This results in 89 percent emission reduction for steel by 2032, 68 percent emission reduction for aluminum by 2032, 32 percent emission reduction for manufacturing by 2032, and 46 percent emission reduction for batteries by 2032.

6.3 Scenario 3

Combined emissions impact

Together, all levers and their least aggressive scenario showcase the risk in not being ambitious enough in the decarbonization of the passenger vehicle industry. Prolonging the transition results in an overshoot of more than 30 percent even though all levers are pulled.

Admittedly, even scenario 3 is ambitious in comparison to previously conducted industry reports and most communicated environmental targets among OEMs. Despite this, the model suggests it is not enough to ensure Paris Agreement compliance, accentuating the importance of accelerating transition through the suggested actions that this report outlines (see figure 19).

Lever 1 – Transition to ZEV. Uses ICCT's most ambitious scenario, providing a more conservative benchmark compared to scenario 1 and 2, projecting full adoption of BEV sales by 2050.[43]

Lever 2 – Fossil-free energy. Scenario 3, IEA Net Zero Emissions, assumes 100 percent fossil-free energy use in the use phase by 2050, with linear extrapolation between 2023 and 2050.

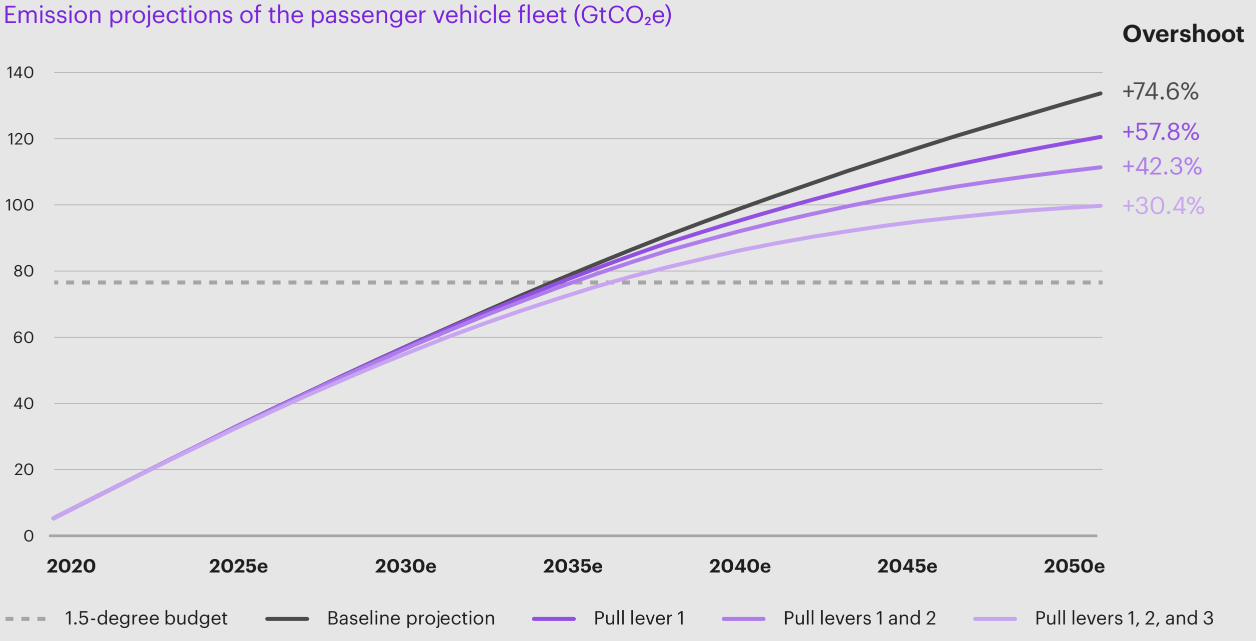
Lever 3 – Reduce supply chain emissions. Like scenario 2, but full fossil-free electricity by 2050 resulting in same reductions achieved but delayed until 2050.

[43] ICCT, 2022; Accelerated-ZEV-transition-wp-final.pdf (theicct.org)

Figure 19

Scenario 3 showcases the risk in not being ambitious enough in the decarbonization of the passenger vehicle industry

Emission projections of the passenger vehicle fleet ($GtCO_2e$)



Source: Kearney analysis

7 Data table with sources

	Topic	Description	Source	Use
Vehicle fleet projection	Vehicle fleet	Historic and projected vehicle fleet (2000–2031)	IHS Markit	Key source
	Vehicle sales	Historic and projected sales (2005–2029)	IHS Markit	Key source
	Vehicle sales	Historic and projected vehicle sales by powertrain (2010–2021)	IEA	Triangulation
	Vehicle sales	Historic and projected vehicle sales by powertrain and size (2017–2034)	LMC Automotive	Triangulation
	Vehicle sales	Historic vehicle sales for BEV and HEV (2004–2021)	Marklines	Triangulation
	Vehicle sales mix	Current and future powertrain mix (2021, 2030, 2040, 2050)	ICCT	Triangulation
Estimation of 2021 life cycle emissions	LCA	Open data source with LCA of European cars (2020–2022)	Green NCAP	Key source
	LCA	Report with LCA data from different geographic regions (2021)	ICCT	Key source
	LCA	LCA data on Polestar and Volvo cars from public report (2021)	Polestar LCA	Key source
LCA development	GHG intensity of electricity grid	Current data on average life cycle CO_2 equivalent emissions of electricity generation technologies (2021)	IPCC	Key source
	GHG intensity of electricity grid	Global average life cycle GHG emissions of electricity generation technologies (2021)	ICCT	Triangulation
	Electricity mix	Global average usage shares of electricity generation technologies (2020–2050)	IEA	Key source
	Fuel economy	Fuel economy improvements in major markets (2005–2017)	IEA	Key source
Budget	Carbon budget	Global CO_2 emissions 2021 and 1.5-degree aligned budget for 2021–2050	IEA, IPCC	Key source

Notes: IEA is International Energy Agency. ICCT is international Council on Clean Transportation. LCA is life cycle assessment. GHG is greenhouse gas. IPCC is Intergovernmental Panel on Climate Change.

Source: Kearney analysis

About Polestar

Polestar (Nasdaq: PSNY) is the Swedish electric performance car brand determined to improve society by using design and technology to accelerate the shift to sustainable mobility. Headquartered in Gothenburg, Sweden, its cars are available online in 27 markets globally across North America, Europe, and Asia Pacific. The company plans to create the first truly climate-neutral production car, without offsetting, by 2030.

Polestar 2 launched in 2019 as the electric performance fastback with avant-garde Scandinavian design and up to 350 kW. Polestar 3 launched in late 2022 as the SUV for the electric age—a large high-performance SUV that delivers sports car dynamics with a low stance and spacious interior. Polestar plans to release three more electric performance vehicles through to 2026.

polestar.com

About Rivian

Rivian exists to create products and services that help our planet transition to carbon neutral energy and transportation. Rivian designs, develops, and manufactures category-defining electric vehicles and accessories and sells them directly to customers in the consumer and commercial markets. Rivian complements its vehicles with a full suite of proprietary, value-added services that address the entire lifecycle of the vehicle and deepen its customer relationships.

rivian.com

About Kearney

Kearney is a leading global management consulting firm. For nearly 100 years, we have been a trusted advisor to C-suites, government bodies, and nonprofit organizations. Our people make us who we are. Driven to be the difference between a big idea and making it happen, we help our clients break through.

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