Master's Thesis – master Sustainable Development
GEO4-2321/GEO4-2322

Greenhouse gas emission coverage and reduction potentials of scope 3 emissions in car manufacturing

To what extent do the current climate targets presented by car companies compare to national climate action under the Paris Agreement?

Jelle Smeets (6270573)

MSc Sustainable Development

Track Energy & Materials

Utrecht University

Copernicus Institute of Sustainable Development

Utrecht University, the Netherlands

Supervisors: Dr. Robert Harmsen & Drs. Mark Roelfsema

NewClimate Institute

Cologne, Germany

Supervisor: Dr. Takeshi Kuramochi

16 November 2022

This Master's thesis is dedicated to my beloved uncle, who has always served as an example in both my personal and professional life. The memory of your enthusiasm about my work has kept me determined to reach the finish line no matter how many setbacks may occur.

Abstract

In the car sector, total greenhouse gas emissions are dominated by indirect emission sources across complicated car supply chains. All indirect emissions fall under scope 3 of the GHG Protocol reporting standards and can be divided over upstream and downstream activities. Corporate reporting of these scope 3 emissions, however, is generally low, complicating possible estimations of reduction potentials for this emission category. Therefore, this Master's thesis assesses the current ambition of major car companies on reducing scope 3 emissions and the current state of their announced reduction targets. We investigated the current target landscape until mid-2022 and the total emission coverage of these targets in car supply chains. In addition, we conducted an in-depth analysis of upstream reduction strategies from the car companies' sustainability reporting and calculated potential emission reductions based on electric vehicle (EV) targets in five of the leading global car markets until target year 2030. Quantification of reduction potentials from upstream steel and EV battery strategies was limited because of data availability and the lack of upstream targets from car companies. The low coverage of upstream scope 3 emissions further resulted in a maximum of 15% of potential uncovered emissions in car manufacturing. In contrast, downstream scope 3 emissions were covered more extensively through multiple reduction targets and the continuous updates of company EV sales targets. Under most recent EV targets, we found significantly higher targeted EV shares in comparison to national policies defined under the Stated Policy Scenario (STEPS). Integrating increased EV uptake in the calculation model resulted in reductions of 64, 77 and 90 Mt of CO_2 for China, the US and the EU respectively, whereas Japan and India achieved low reductions of 3 and 1 $MtCO_2$. In conclusion, more upstream reduction targets and overall transparency of supply chain innovations are required for an optimal coverage of scope 3 emissions and quantification of reduction potentials. Furthermore, we recommend better uptake of corporate EV targets in national policies to align with the rapid EV development. Although car companies showed limited upstream coverage, we argue that their downstream targets can provide an example of better national policies towards decarbonization of the car sector in this decade.

Statement on additional data

Part of the methods in this Master's thesis were carried out with the use of an Excel-based model. Additional data sources and detailed model calculations were included in the Excel files that are accessible via the citation below. CDP responses were not included in these files.

> Smeets, Jelle. (2022). *Supplementary data on car company reduction target analysis and GHG emission model* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.7327596

List of abbreviations

APS = Announced Policies Scenario

BEV = Battery electric vehicle

EV = Electric vehicle

EVI = Electric Vehicles Initiative

FCEV = Fuel cell electric vehicle

GHG = Greenhouse gas

HEV = Hybrid electric vehicle

HSS = High-strength steel

ICEV = Internal combustion engine vehicle

LCA = Life cycle assessment

LIB = Lithium-ion battery

MSR = Material substitution ratio

NDC = Nationally determined contribution

NSA = Non-state and subnational actors

PHEV = Plug-in hybrid electric vehicle

SBTi = Science-Based Targets initiative

SSB = Solid state battery

STEPS = Stated Policies Scenario

TTW = Tank-to-wheel

UHSS = Ultra high-strength steel

USP = Use of sold products

WTT = Well-to-tank

WTW = Well-to-wheel

ZEV = Zero emission vehicle

Table of contents

1. Introduction

1.1. Background

The Paris agreement in 2015 created an important incentive for major global economies in the ongoing efforts to mitigate greenhouse gas (GHG) emissions and reduce the effects of climate change. While more national governments have now documented their climate ambitions in this agreement, the role of non-state and subnational actors (NSAs) such as cities, regions or businesses is less straightforward (Hsu et al., 2019). Since the combined targets of national governments will likely be insufficient to keep global temperature levels well below 2°C or 1.5°C, this resulting 'emission gap' between the aggregate of national contributions and the targeted emission levels remains large and requires further climate action to bridge it (UNEP, 2021). Therefore, non-state climate action beyond national government policies and targets must seriously be considered and may provide much-needed contributions to climate change mitigation.

Potential GHG reductions from these NSA initiatives may affect existing policies on national level. For instance, analysis by Kuramochi et al. (2020) shows how individual NSAs could contribute to an additional reduction factor of 1.2 – 2.0 $GtCO_2e$/year in 2030 below projected levels of implemented policies. For NSAs with international collaborative action these estimations are even higher, with a maximum reduction potential of 21 $GtCO_2e$/year (Lui et al., 2021). As more aggregation studies have provided attempts towards a better understanding of their potential, NSAs are increasingly regarded as crucial tools for policy makers to help reach nationally determined contributions (NDCs) and set more ambitious goals (Andonova et al., 2017; Lui et al., 2021). Nonetheless, this research field is still prone to uncertainties that complicate an accurate comparison of aggregation studies. Due to varying terminologies and methodology choices (e.g. scope selection, reference data and accounting for overlap), there is still limited information about the actual impact of implementing NSA climate action (Hale et al., 2021; Hsu et al., 2019).

As non-state actors that may easily exceed national borders, companies are an important and potentially influential power in climate mitigation. Like other NSAs, companies increasingly participate in setting new GHG reduction targets following commitments of individual countries. This led to a rise of various initiatives pursuing non-state action at company level such as the Science Based Targets initiative or Race to Zero (NewClimate Institute et al., 2021; SBTi, 2021; UNEP, 2021). Simultaneously, companies are increasingly reporting their GHG emissions. Assessing and reporting of GHG inventories for companies relies on a corporate standard, distinguishing direct (scope 1) and indirect (scope 2 and 3) GHG emissions based on resource ownership (Greenhouse Gas Protocol, 2004). Because scope 3 emissions are by definition another company's scope 1 or 2 emissions, the growth and relative share of scope 3 emissions has been significant, predominantly in developing countries and for industry, building and agriculture sectors (Hertwich & Wood, 2018). Moreover, scope 3 emissions are crucial to understand for climate mitigation as many manufacturing industries often rely on 'hard-to-abate' sectors where the feasibility of full decarbonization is challenged by emission-intensive processes such as cement and steel making (Climate Action Tracker, 2017; IEA, 2020). These emissions are not defined as the reporting company's direct emissions, which poses the question whether they are fully covered by that company's climate ambitions. Further understanding of scope 3 GHG emissions from fossil fuel-dependent industries could therefore provide an important step towards their full decarbonization.

One clear example of a carbon-intensive non-state actor heavily impacted by scope 3 emissions is car transportation. Total transportation emissions currently contribute to roughly 25% of global GHG emissions and have been growing steadily in the 21st century (IEA, 2021b). Light-duty vehicles alone were responsible for 40% of transport emissions in 2020 (Kong et al., 2021). With almost all emissions in a vehicle's lifetime caused by upstream supply chains and downstream fuel consumption during its use, better coverage of scope 3 emissions is crucial to mitigate climate impacts from cars (Stephan et al., 2019). Moreover, this sector has a clear reliance on hard-to-abate industries that complicate supply chain decarbonization, for example through excessive steel use in cars (Qiao et al., 2019). Therefore**,** the sector's characteristics provide a key opportunity where further research on scope 3 emissions and quantification of GHG reduction potentials is needed for a better understanding to help filling global emission gaps.

1.2. Problem definition and knowledge gap

While the ongoing decarbonization efforts in car transportation exceed those of other transport modes, a successful decarbonization pathway also requires a combination of additional reduction strategies for cars. Powered by the rise of electric mobility, car transportation has shown rapid development compared to other transport modes like shipping and aviation, which need more decarbonization efforts to limit their emission levels (UNFCCC, 2021). A pathway to zero-carbon in 2050 is therefore feasible for the car sector.

However, most implemented policies to reduce emission from cars still do not align with Paris goals. For example, analysis by IIGCC & 2DII (2020) estimated that only 14% of the individual production plans from large global car companies was aligned with scenarios below 2°C. Additionally, the sector shows further stagnation in timely phasing out fossil fuel-based internal combustion engine vehicles (ICEV) in favour of electric vehicles (EVs). Vehicles show little progress in fuel efficiency, significant data gaps between test and actual on-road data and companies hesitate to move beyond their business perspective of continuously expanding the total fleet (Stephan et al., 2019). Finally, whereas more governments and car companies are formulating reduction targets, climate organizations argue that the sector's strong lobby against further climate regulation is simultaneously preventing the industry's necessary transition (ICCT, 2021). For a pathway consistent to Paris goals, the fourteen companies included in the aforementioned analysis must produce 28.7 million additional EVs and hybrids and 43 million fewer ICEVs before 2024 (IIGCC & 2DII, 2020). In addition, leading car markets must aim for a light-duty vehicle EV sales share of 75% by 2030 to keep a zero-carbon sector by 2050 in sight (UNFCCC, 2021). In conclusion, immediate ICE phase-outs are needed to limit transportation emissions and remain aligned with Paris goals.

Next to the global decarbonization challenges of car transportation we examine more specific challenges of corporate scope 3 emission reporting. Because most GHG emissions attributed to car companies currently originate from scope 3 emissions of used products rather than direct company operations, supply chain decarbonization is required (NewClimate Institute et al., 2021). Despite significant emissions embedded in upstream activities, accurately reporting upstream scope 3 emissions is challenging due to the reliance on manufacturer and supplier data provided to reporting companies (Greene, 2017). This lack of transparency severely complicates assessing GHG emissions for not only car manufacturing but NSA aggregation studies in general, because scope 3 emissions cannot always be included in the methodology (as shown by Kuramochi et al. (2020) & NewClimate Institute (2021)). Car manufacturing is no exception: car companies often do not or only partially disclose supplier data (Kong et al., 2021; Stephan et al., 2019). Therefore, the upstream knowledge gap for this analysis refers to the degree of data disclosure and overall transparency in corporate emission reporting.

Downstream emissions are less susceptible to corporate data reliance because independent statistical offices report downstream data such as the average fuel use and person-km of cars. Nonetheless, car companies must still take effort to report GHG emissions after vehicle delivery to customers, where most emissions take place. Downstream emission targets for car manufacturing have been explored recently, but we aim to revisit these findings with updated data to cover the recent development in the rapidly changing target landscape. The current downstream knowledge gap thus refers to what extent car companies cover GHG emissions through their targets and how the latest company targets compare to the fuel performance and electric mobility targets of national policies under global climate agreements.

1.3. Research aim and relevance

The current research focuses on establishing the current knowledge of scope 3 emission reporting and assessment of GHG reduction targets in the car manufacturing sector. Reporting of scope 3 emissions is currently unsatisfactory, limiting available research on NSA aggregation and supply chain emission coverage. The main objective of this study is to investigate the ambition of major car companies on their supply chain emission reductions. Under this general objective, we aim (1) to assess overall existence of short and long term reduction targets, (2) to estimate the GHG emission coverage by these targets, including an in-depth analysis on upstream emissions which are often overlooked in policy discussions, and (3) to quantify the aggregate impact of selected car companies' targets on future emissions in comparison with country projection under national policy scenarios.

The results of this study must add to the latest NewClimate/Utrecht University research, which is focused on identifying additional GHG reductions from individual car companies' targets compared to those implied by national government targets. The current research adds further relevance by updating initial results and extending the analysis to other emitting countries for a more complete understanding of reduction potentials coming from car manufacturing. Furthermore, we aim to include the upstream effect of targets into GHG reduction potentials, building upon recent aggregation studies for non-state climate action, e.g. Kuramochi et al. (2020) & Lui et al. (2021). The results can contribute to ongoing efforts of analysing and improving the limitations of NSA research. Inspired by the work of Hale et al. (2021), Hsu et al. (2019), & Smit (2019), it seeks further solutions to optimally integrate NSA climate action into more ambitious NDCs to keep global temperature levels limited.

1.4. Research questions

The following research question has been developed based on the knowledge gap above:

> ***What is the upstream and downstream greenhouse gas reduction potential of current and announced car companies' targets compared to national policies alone?***

The GHG reduction potential of the car sector is based on assessment of ten car manufacturing companies and their current upstream and downstream scope 3 emission reduction targets until target year 2050. The comparison with national policies is based on a downstream assessment on electric mobility until target year 2030 in the top five global car markets. These choices are further explained below.

1.4.1. Company selection

The analysis covers the ten global car companies with the largest estimated global sales in 2020 (see table 1). Total sales from these ten companies were 54.54 million units covering 80% of global sales in that year (Kong et al., 2021). Table 1 further presents findings of the car companies' carbon footprint in 2018. These carbon footprints were calculated as the sum of tailpipe, upstream, production and recycling emissions that were derived with individual data on car sales and average fleet emissions per analysed country. The ten largest car companies alone were responsible for a total of 3.95 $GtCO_2e$ across the world. As a consequence, the combined action of the top car companies can have an impact on global emissions comparable to all EU member states, emitting 4.1 Gt in 2018 (Stephan et al., 2019).

Table 1. The ten largest car manufacturing companies based on 2020 sales (in blue) and 2018 carbon footprints (in green). Data was retrieved from Kong et al. (2021) & Stephan et al. (2019).

Car manufacturer	Car sales 2020 (million units)	Carbon footprint in 2018 ($MtCO_2e$)	Emissions per vehicle in 2018 (tCO_2e)
1. Toyota	8.85	562	53.8
2. Volkswagen	8.75	582	53.8
3. General Motors	6.93	530	61.3
4. Stellantis[1]	6.16	506	56.2
5. Hyundai-Kia[2]	6.13	401	54.0
6. Honda	4.46	283	54.1
7. Ford	4.24	346	61.4
8. Nissan[3]	3.75	577	55.7
9. Renault[3]	2.61		
10. Mercedes-Benz	2.52	161	58.7
Total top 10	**54.54**	**3,948**	

Table notes

1. *From 2021 onwards, PSA and FCA have merged into Stellantis. Stellantis' 2018 emission data in table 1 is equal to the sum of PSA's (305 Mt) and FCA's (201 Mt) carbon footprint, still reported separately by Stephan et al.*
2. *The Hyundai-Kia collaboration group of individual car brands is regarded here as one company because of shared technologies, vehicle platforms and development strategies.*
3. *Whereas Stephan et al. calculated the footprint of the entire Renault-Nissan Alliance, this report follows the argumentation made by Kong et al., who argue that the rate of independence between its companies is too high to define this alliance as one company.*

The ten selected car companies are included in the in-depth upstream analysis and the downstream sales analysis of this research. However, upstream and downstream approaches of assessing reduction potentials differ from each other based on available corporate targets and strategies. As a result, a country selection is only used in the downstream part of the research because of the complexity and the hypothesized limitations of many upstream impacts that cannot easily be quantified. To distinguish these upstream and downstream impacts the four sub-questions were divided as follows:

Part 1: Upstream scope 3 emissions

- **I. What is the upstream coverage of EV battery and steel production in the current reduction measures of car companies?**
- **II. What is the upstream potential of scope 3 targets in the car manufacturing industry?**

Part 2: Downstream scope 3 emissions

- **III. What downstream reduction targets exist for the ten largest car companies in the five largest global economies and how do they compare with national policies?**
- **IV. What is the downstream GHG potential of scope 3 targets in the car manufacturing industry?**

Part 1 includes an assessment of current upstream scope 3 emissions and investigates possible improvements in the complex upstream car manufacturing supply chains. As stated above, specific upstream reduction targets may be limited. Alternatively, the upstream section includes an assessment of car company strategies about crucial car components steel and EV batteries through in-depth analysis of corporate sustainability reporting.

In part 2, reduction potentials are based on sales targets for battery electric vehicles (BEVs) and plug-in electric hybrid vehicles (PHEV) combined with phase out policies of conventional cars. Unlike part 1, we introduce a national perspective for the downstream analysis. A quantitative estimation of GHG emission reductions is made based on EV sales targets and national market shares of car companies in the selected regions. Furthermore, the downstream GHG reduction potential specifically refers to the additional reductions that can be achieved when company targets are reached and added to current national policies already in place.

1.4.2. Downstream emission region selection

Similar to the company selection, the country selection is based on the largest global car markets. The largest five regions were included in the analysis. Table 2 shows the market shares of these regions on a global level (ICCT, 2021). The top five markets covered 78% of passenger car sales in 2020. Furthermore, we based this selection on recent findings in scientific literature. Quantitative analysis on downstream car manufacturing impacts by NewClimate Institute et al. (2021) assessed the potential of EV sales targets from car companies relative to a national policy baseline in the three largest car markets: the European Union plus the United Kingdom (EU27+UK), the United States and China. We include Japan and India into the downstream part of the current study as the fourth and fifth leading market for new passenger cars in 2020. Finally, these five regions largely differ in carbon intensity of grid electricity which is also modelled in IEA's future scenarios (IEA, 2021d; Märtz et al., 2021). Therefore, the country selection provides additional insights of corporate EV targets impacted by the EV use phase in different locations.

Table 2. 2020 Market shares of top five global economies in car manufacturing (retrieved from ICCT, 2021)

Region	**Market share (% of new sales in 2020)**
China	31%
United States	22%
European Union + United Kingdom	15%
Japan	6%
India	4%
Total top 5	**78%**
Rest of world	*22%*

In conclusion, corporate reduction targets from the ten car manufactures in table 1 are included in both parts of the research. However, the region selection in table 2 is only used in the downstream part of the research. Further explanation and more detailed upstream and downstream methods can be found in chapter 3.

2. Theory

This chapter describes the relevant terminology and definitions in the car manufacturing sector which is used to form an adequate research methodology in chapter 3. First, it highlights important definitions on NSA climate action and scope 3 emission reporting in recent literature. Second, it describes the structure and characteristics of the full car manufacturing sector and the corresponding upstream and downstream activities in the car supply chain.

2.1. Corporate climate action and overlap with national policies

Climate action from individual corporations differs from national or government actors, such as cities, states, and regions. Where cities, states and regions form typical subnational actors, businesses are major non-state actors (Lui et al., 2021). Apart from individual actors, non-state climate action also includes efforts from international cooperative initiatives (ICI) with multiple actors collaborating on climate action beyond national borders (NewClimate Institute et al., 2021).

Potential overlaps between individual targets and national policies are crucial to understand because corporations – like other individual actors – can simultaneously be part of one or more ICIs. This aspect contributes to ongoing debate among policy makers about whether NSAs and ICIs must be considered complementary or parallel to national climate action (e.g. in Andonova et al. (2017) and Roger et al. (2017)). Following ongoing research recommendations on addressing interactions between similar actors, overlap can occur when (1) actors target the same location, sector and GHGs (i.e. geographical overlap) and (2) when the same emission source is targeted either from a supply-side or use perspective (i.e. value chain overlap). Defined overlaps, however, can also have an additional reinforcing effect on climate ambition when the overlapping actors show different levels of ambition, which is known as additionality (Hsu et al., 2019). Different methodologies on assessing overlap and additionality may lead to notable differences in estimated ranges of GHG reduction potentials or accidental double-counting of emissions. In addition, transnational NSA ambitions can significantly overlap NDCs, as argued by Roelfsema et al. (2018), who estimated a maximum overlap potential between international NSA initiatives and the adoption of NDCs in the Paris Agreement of 80% in 2030.

It is therefore necessary that these overlaps are accounted for in emissions assessment to accurately assess their combined impact on emission reduction potentials. In this report possible overlaps between corporate and national climate action are accounted for in the downstream analysis calculation of this report, where corporate EV sales targets are compared to national stated policies. Because the research objective focuses on individual company ambitions, we do not further assess ICIs nor other non-state actors beyond companies.

2.2. GHG emission reporting

The standardized methodology of corporate emission reporting follows the terminology and description of the corporate emission standard in the Greenhouse Gas Protocol. This protocol is aimed at companies to calculate, report and analyse GHG emissions from the product, services and value chains for which they are responsible. Company GHG emissions are categorized in three separate emission scopes, visualized in figure 1. According to this protocol, the scopes were introduced *“to help delineate direct and indirect emission sources, improve transparency, and provide utility for different types of organizations and different types of climate policies and business goals”* (Greenhouse Gas Protocol, 2004, p. 25).

- Scope 1 emissions are defined as all *direct* emissions, i.e. all GHG emissions resulting from sources owned by the reporting company;

- Scope 2 emissions are defined as the *indirect* emissions resulting from the company purchasing electricity, heating or steam for their own energy use;
- Scope 3 emissions are defined as all other *indirect* emissions resulting from sources not owned by the company but linked to its operations, e.g. material extraction, production of purchased resources elsewhere or transportation emissions (Greenhouse Gas Protocol, 2004).

Scope 3 emissions can be divided further into upstream and downstream emissions. From a reporting company's perspective, upstream emissions occur in all processes related to purchased goods and services and downstream emissions occur in all processes related to the products and services sold to customers. In total, fifteen subcategories of upstream and downstream scope 3 emissions exist (see Greene (2017) & figure 1). Currently, reporting of scope 3 emissions is still considered voluntary in the established corporate standard. However, in 2011 the GHG Protocol published a separate standard for scope 3 reporting with the aim of further stimulating a company's motivation to report scope 3 emissions (Greenhouse Gas Protocol, 2011). Nonetheless, adequate research on scope 3 emissions is still heavily dependent on the amount of data disclosure that companies have reported.

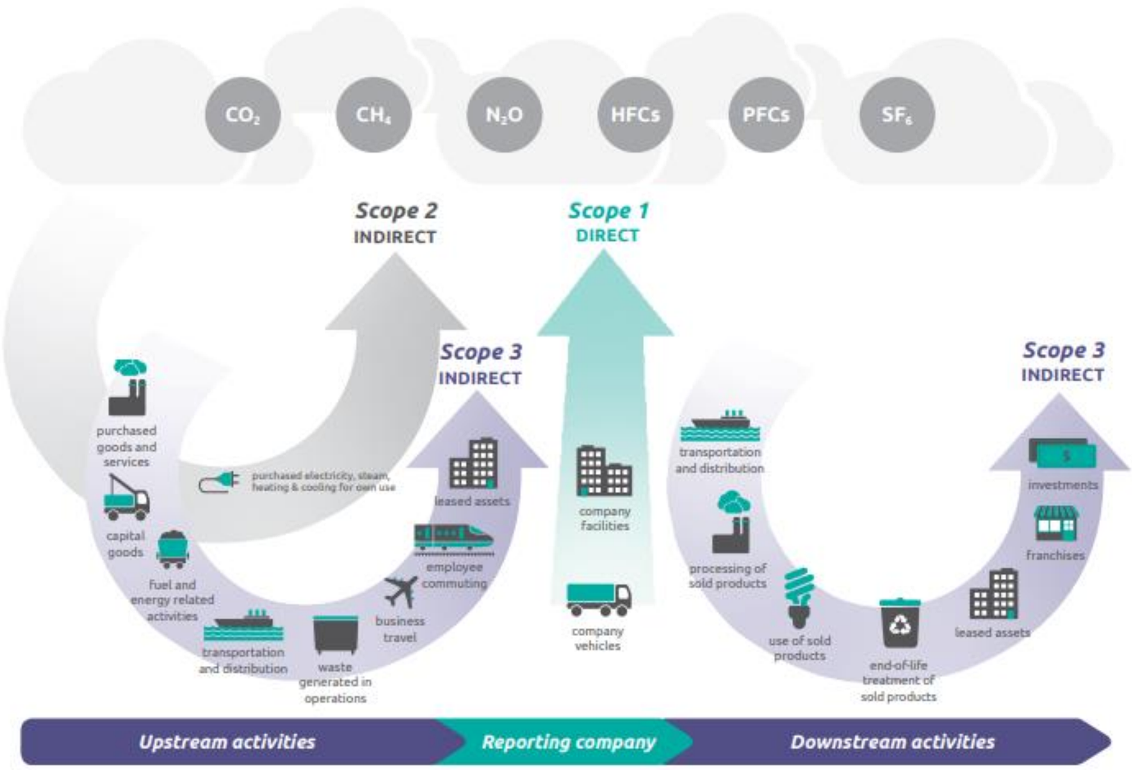


Figure 1. Visualization and examples of scope 1, 2 and 3 emissions according to the GHG protocol (retrieved from Greenhouse Gas Protocol, 2011).

The Greenhouse Gas Protocol is used to uncover direct and – most notably – indirect emissions on company-wide level. As such, implementing the corporation emission standard can help independent statistical offices to report on the real emission levels of companies and their value chains. In turn, climate targets can be created to maximize the total emission coverage of a company's targets. One key organization on collection of corporate GHG reporting is CDP (formerly Carbon Disclosure Project). CDP's databases contain extensive company data on climate action. Companies report current emissions and reduction targets to CDP's extensive questionnaires together with supplementary explanations. Reported car company data in CDP questionnaires is therefore a prerequisite for the creation of GHG emission inventories. In turn, these inventories are necessary to enable further analysis on the coverage and reduction potential of corporate climate targets in this study.

2.3. Emission perspectives: life cycle & car supply chains

Moving beyond corporate level, further understanding of car manufacturing from a product's perspective is needed to find the relationship between corporate scope 3 emissions and their impact in a car's lifetime. We now introduce the product perspective of GHG emission assessment in comparison to scope 1, 2 and 3 emissions from corporate reporting standards. Life cycle assessments (LCAs) are the most common tool of assessing impacts in every life cycle step across various impact categories. Life cycle emissions include all emissions during a product's lifetime, such as raw material extraction, manufacturing, transport, storage, sale, use and disposal activities. LCAs provide a lifetime system perspective of a product rather than an annual assessment of corporate emissions for a specific entity (EPA, 2016). ISO standards used in most LCAs slightly differ from product standards in the GHG protocol (Weidema, 2022).

LCAs and emission inventory reporting with GHG Protocol standards are two widespread methods for estimating environmental impacts. Both approaches have optimal uses and do not substantially differ in accuracy. For companies, a combination of GHG inventories and life cycle assessments can be useful. For scope 3 emissions in particular, life cycle approaches may even improve detailed input and in-depth coverage of emission used in GHG inventories (Arshi & Sinistore, 2022). Although addressing similar concepts and activities, a product's life cycle emissions are not necessarily equal to a company's scope 1, 2 and 3 emissions defined previously. According to the GHG Protocol, *"the sum of the life cycle emissions of each of a company's products, combined with additional scope 3 categories (e.g., employee commuting, business travel, and investments), should approximate the company's total corporate GHG emissions (i.e., scope 1 + scope 2 + scope 3)"* (Greenhouse Gas Protocol, 2011, p. 8). As a result, scope 3 emissions include certain corporate-specific activities like employee commuting and investments which are less relevant from purely a product's perspective.

Additionally, the terms supply chain and value chain are widely used to refer to the sequence of activities in a product's or company's operations. In consulted literature, 'supply chain' and 'value chain' are often used inconsistently and interchangeably to address similar concepts. According to GHG protocol terminology, 'supply chain' specifically includes a *"network of organizations … involved in the production, delivery, and sale of a product to the consumer";* value chains, on the other hand, refer to *"all of the upstream and downstream activities associated with the operations of the reporting company"* (Greenhouse Gas Protocol, 2004, p. 141). Therefore, value chains typically refer to company operations, whereas supply chains refer to a specific product. Figures 2 and 3 below highlight similarities and differences between examples of both concepts in scientific literature.

An additional key characteristic of value chains is the economic perspective. The concept is aimed at adding value with every step (Kaplinsky & Morris, 2001). Financial considerations like marketing services and product design are often featured in value chain figures together with product manufacturing steps included in most supply chains. Because this paper's scope does not include financial considerations, we do not use the specific term value chain emissions to refer to corporate emissions in this way.

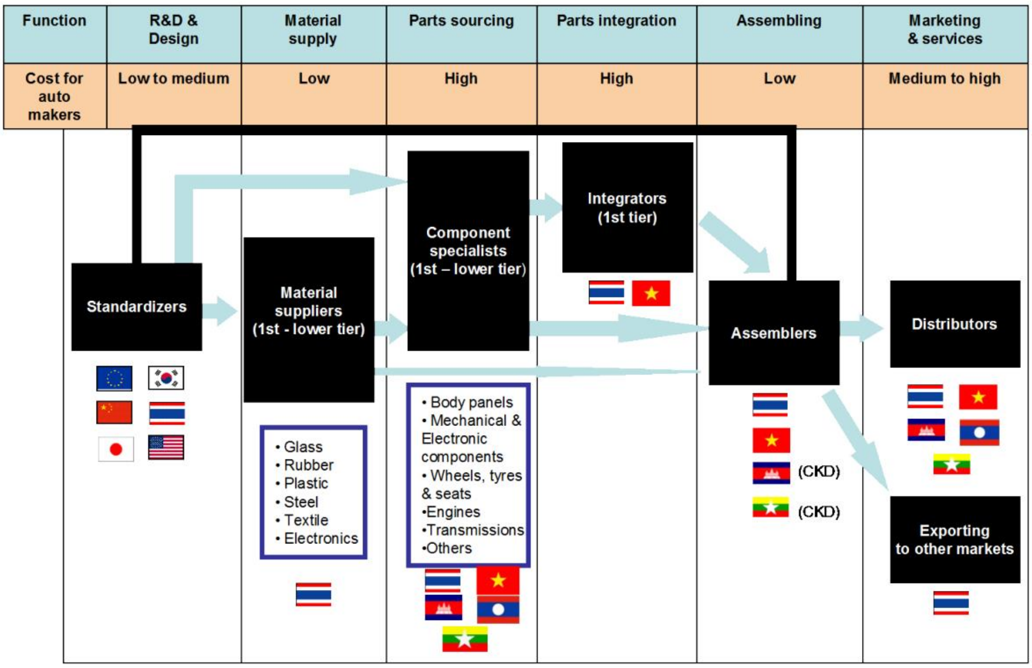


Figure 2. Example of a simplified global automotive value chain (retrieved from Abe, 2013).

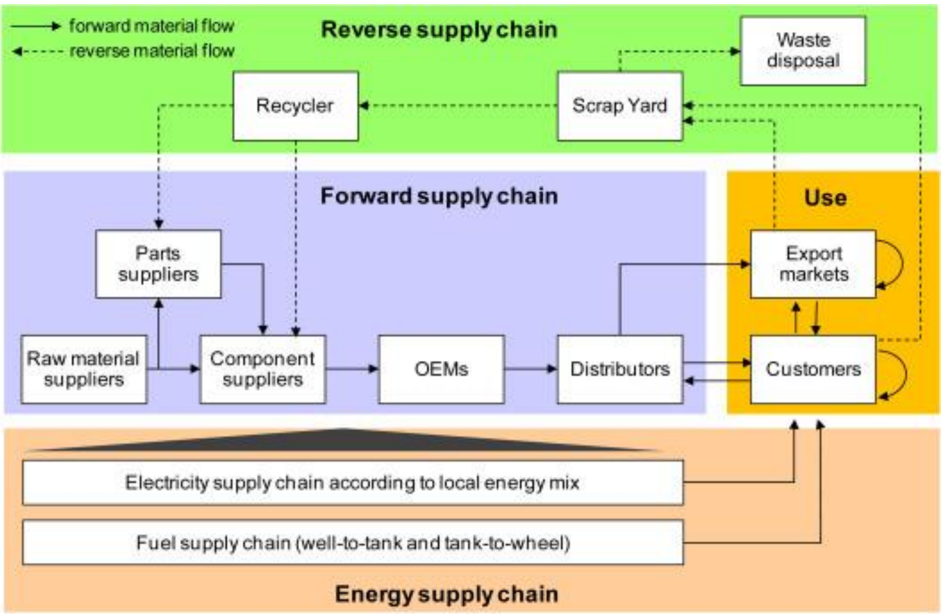


Figure 3. Car manufacturing supply chain including a forward production chain (cradle-to-gate), a use phase including the energy supply chain (well-to-wheel) and a reverse recycling phase (grave-to-cradle) to close the cycle (retrieved from Günther et al., 2015).

Since the research aims to investigate company ambitions, the definitions and method choices are dependent on the way company data is presented. In summary, we use definitions from the GHG Protocol standards, who typically use value chain for company emissions and supply chain for a product's emissions. Even though both concepts are often used interchangeably in practice, the term value chain is not used to avoid confusion between the concepts (we interpreted value chains as mostly economic tool). Furthermore, all companies use the GHG Protocol-based emission scopes to report emissions to CDP. This is the main approach we take for assessing current company emissions. However, we use product-related life cycle emissions fur further specification and categorization of corporate reduction targets. Supply chain categories such as logistics, manufacturing or recycling are only used to introduce emission activities in the next section and to assess supply chain emission coverage of collected targets. These exceptions were based on the collected content of targets, which only sporadically used GHG Protocol emission categories.

2.4. Car manufacturing emissions

The existing body of LCA studies provides a more detailed breakdown of car manufacturing emissions divided over different components in vehicle supply chains. Four main emission sources can be identified in a car's lifetime (Stephan et al., 2019):

1. Upstream supply chain and production emissions during manufacturing;
2. Tailpipe emissions from fuel consumption in the use phase;
3. Emissions from fuel production and supply during the use phase;
4. End-of-life emissions after the active lifetime, e.g. during re-use or recycling.

The first stage is production of the vehicles, including (1) emissions in the raw material supply chain and (2) emissions at the car manufacturing sites itself. Using both raw and recycled materials, car parts and components are created by first-tier suppliers and later assembled by original equipment companies to create the final product. Manufacturing further includes material extraction, processing and vehicle assembly. Most GHG emissions are covered by well-to-wheel (WTW) emissions that consist of well-to-tank (WTT) emissions for fuel production, and tailpipe tank-to-wheel (TTW) emissions for fuel consumption during use (Günther et al., 2015). For ICEVs, WTT emissions cover crude oil extraction to final fuel distribution and TTW emissions refer to direct emissions from fuel combustion. For EVs, these processes are replaced by an electricity supply chain dependent on the local energy mix (European Commission et al., 2020; Günther et al., 2015; Qiao et al., 2017). In figure 3, these energy supply chains are visualized for both car types. Use phase emissions may include vehicle maintenance as well depending on the selected LCA scope. Finally, the end-of-life stage contains options for recycling, re-using and preventing waste generation. Figure 4 includes an example of a cradle-to-grave LCA study in the car sector including WTW, WTT and TTW definitions.

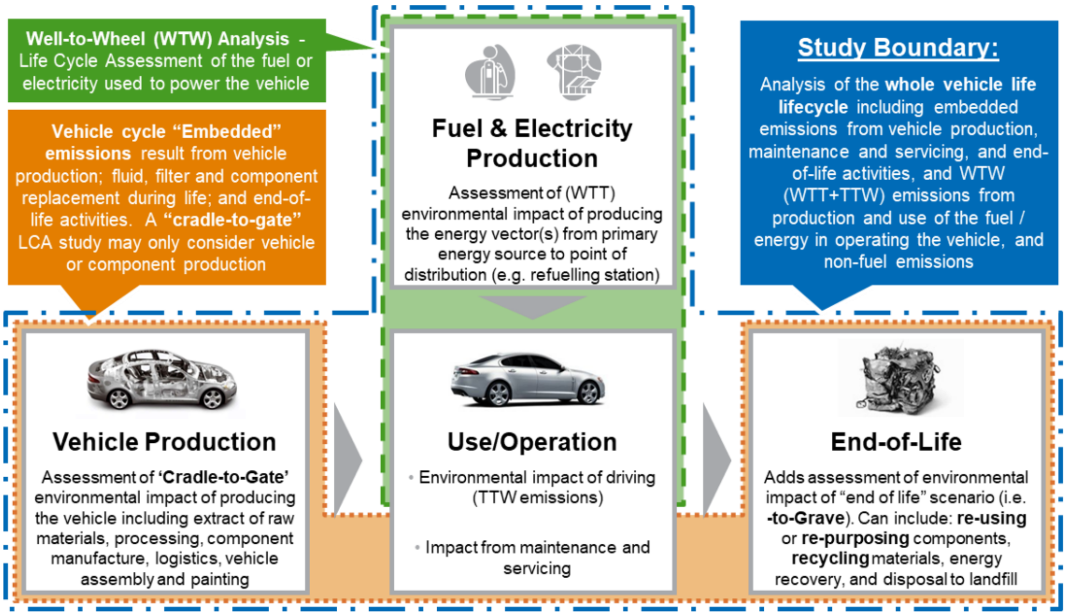


Figure 4. Breakdown of vehicle emission categories in example LCA study (retrieved from European Commission et al. (2020)).

2.4.1. Upstream activities: steel and EV batteries

Despite use phase emissions covering the largest share of vehicle emissions, production of vehicles and related upstream supply chains cannot be neglected. The role of steel in car manufacturing is crucial. Steel is the most abundant material in any passenger car regardless of the powertrain. Steel and iron make up 67% of an ICE vehicle's weight and 53% of its manufacturing (cradle-to-gate) emissions. For BEVs, these percentages are only 6% lower (Kong et al., 2021; Qiao et al., 2017). Resulting from this dependency on steel, any reduction of steelmaking emissions or overall steel use can greatly impact a vehicle's overall life cycle emissions. One possible solution is the improvement of typical emission-intensive production processes, e.g. by implementing more scrap steel or use of hydrogen. However, avoiding steel altogether in favour of less emission-intensive materials within the car is a second solution. By substituting steel parts with suitable alternatives the overall weight of a vehicle decreases, ultimately leading to lower emissions. This is known as lightweighting.

Furthermore, emissions from EV batteries form a large part of upstream emissions. In many cases, electric vehicles cause more emissions during manufacturing than ICEVs because of the additional impact of producing a capable car battery. Battery production impacts often form a deciding factor in determining EV emissions and the benefits compared to ICEVs; in few situations high battery emissions even cause more life cycle emissions (Kawamoto et al., 2019). Lightweighting for batteries also has great potential, as an average BEV battery weighs over 200 kg, up to ten times as much as batteries for hybrids (Deetman, 2021). Moreover, making the vehicle less dependent on common battery components such as lithium, cobalt and nickel leads to further emission reduction from mining and processing these minerals. Therefore, reduction measures from steel and battery production can lead to significantly lower emissions compared to ICEVs throughout the life cycle.

2.4.2. Downstream activities: electric mobility

Upstream activities still have a limited effect on climate action compared to emissions in the use phase. As a result, total emission reduction potentials remain relatively low without reduction of downstream WTW emissions in particular. Electric mobility drastically reduces TTW emissions, but the global car sector is still heavily dependent on fossil fuels. In 2020, 99% of the existing fleet consisted of ICEVs. Nonetheless, the number of EVs saw an exponential increase in the last decade, reaching over 10 million units in 2020 (IEA, 2021a). Total sales in 2021 reached 6.6 million units, doubling the amount of 2020 despite the impact of the Covid-19 pandemic (IEA, 2022c). Despite the projected growth of EV sales and the peak of ICEVs that has been reached already, the latter will still dominate sales in the long term without additional phasing out policies (Kong et al., 2021). The logical choice for car decarbonization is therefore a rapid phase out of ICEVs in favour of using electricity in future transport. Future passenger transport demand and material use will be increasingly dominated by cars compared to other modes of transport (Deetman, 2021). Therefore, implementation of EVs is a crucial step to reduce transportation emissions.

We use the collective term EVs for the sum of BEVs and PHEVs. The second hybrid type, hybrid electric vehicles (HEV), is typically not listed as EV. BEVs, PHEVs and HEVs are sometimes targeted collectively in national or corporate targets under terms such as 'electrified' vehicles, zero emission vehicles (ZEV) or low emission vehicles (LEV). For this analysis we only cover BEV and PHEV shares, so HEVs must be excluded from targeted EV shares when companies or regions included them. The last noteworthy vehicle type is the fuel cell EV (FCEV), which has no tailpipe emissions by relying on hydrogen. FCEVs have potential to reduce future transportation emissions together with BEVs and already integrated in future plans of certain carmakers like Hyundai-Kia (Hyundai, 2021; Kia, 2021). However, FCEVs are not yet produced on a large scale, so we excluded this vehicle type as possible EV development in this research.

There is already a large number of life cycle assessment (LCA) studies to calculate and compare GHG emissions of ICEV and EV production, use and end-of-life stages. Total GHG emissions for EVs are heavily dependent on the carbon intensity in the supplied electricity mix, overall efficiency and further region-specific conditions such as weather or driving patterns. As a result, EV emissions also vary regionally and can show major differences in environmental performance when compared to ICEVs across multiple regions (Kawamoto et al., 2019; Märtz et al., 2021). Despite differences in scope and methodology, numerous LCA results show a clear trend of lower environmental impacts from all EV types compared to ICEVs (European Commission et al., 2020). Moreover, even under current carbon intensities and development level of decarbonization in end-use electrification, introducing more EVs can already lead to lower GHG emissions in 90% of world regions (Knobloch et al., 2020). Furthermore, PHEVs have shown emission reductions compared to ICEVs, but their reduction effect in climate mitigation is heavily debated. Despite some car companies' trust in hybrids, hybrids have a limited reduction factor of GHG emissions compared to the potential reduction from fully electric cars and cannot be regarded as an adequate solution for decarbonizing transport. Furthermore, real-life emission values of hybrids are often higher than the calculated theoretical values (Kong et al., 2021; Stephan et al., 2019). Recent analysis on 9000 European PHEVs by Plötz et al. (2022) showed that PHEVs consume three to five times more fuel than the averages approved in the latest fuel economy standards, leading to a large difference in tailpipe emissions. While adopting hybrids can bring emission reductions compared to conventional ICEVs, they should thus solely be used as short-term intermediate solution for phasing out ICEVs in favour of BEVs (Bieker, 2021). In the long term, BEVs and FCEVs will likely shape the electric vehicle market.

3. Methods

This methods of this study consisted of GHG emission reduction potential assessments for both upstream and downstream scope 3 emissions in car manufacturing. In the first part we identified current emission inventories based on corporate emission reporting. Emission reduction targets of the ten selected companies were collected and analysed hereafter. Company climate targets were divided over car supply chain emission categories and translated into percentual estimates of scope 3 emission coverage. Possible reduction potentials were specified for upstream and downstream activities. Upstream potentials were focused on the impact of steel use in cars and battery production for EVs in particular. A first upstream research attempt was made to explore the range of potential GHG emission reductions from these two components covered by sustainability reports and scientific literature. In the last section we assessed reduction potentials of downstream emissions through quantitative modelling. The model estimated GHG emissions under most recent company EV sales targets in key markets compared to a reference scenario under national pledges. Figure 5 summarizes the research methodology.

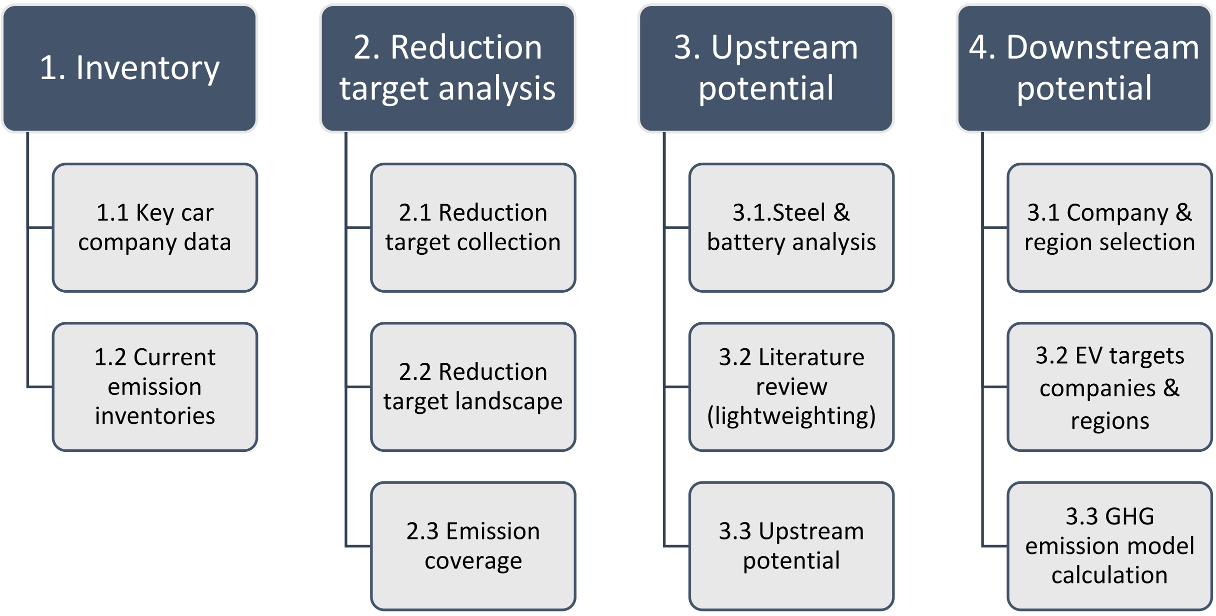


Figure 5. Paper methodology divided over four research steps.

3.1. Emission inventory

Before the reduction potential assessment we attempted to create emission inventories of scope 1, 2 and 3 GHG emissions of car manufacturing. This emission inventory served as input for the target analysis, target emission coverage and the creation of a reference scenario in later research steps. Company emission data was gathered from CDP questionnaire responses and individual company sustainability reporting. CDP data included company-wide emission inventories reported in climate change questionnaires (CDP, 2020, 2021). The questionnaires and responses of reporting years 2020 and 2021 were both included in this study. In the questionnaire's section on GHG emissions, companies disclose overall scope 1, 2 and 3 emissions from their activities. Reported scope 3 emissions are also divided over all subcategories featured in the GHG Protocol standards.

Next to CDP questionnaire responses we included sustainability reporting published by the companies. As main annual publication on corporate climate action that is publicly accessible, sustainability reports can be an important and transparent information source on corporate emissions. Similar to CDP data, sustainability reports included 2020 and 2021 versions. The included selection was based on the publication date which was different per each car company. We included all sustainability reports that were published before the cut-off date of 1 June 2022. This included most of the recent sustainability reports for 2021 which were mostly published in the first months of 2022. Alternatively, 2020 versions (published in 2021) were used when the 2021 version had not been published before the cut-off date.

3.2. Company target analysis

The second step included collection of current emission reduction targets and categorization of collected targets in the car supply chains. The aim of this section was to analyse the current landscape of targets and estimate the emissions that were covered by the company targets in place.

3.2.1. Reduction target collection

For all ten companies presented in table 1, emission reduction targets until target year 2050 were collected and categorized as a first estimation of total emission coverage of current pledges. The same dataset of CDP responses and sustainability reports was used for collection and documentation of included targets, meaning all targets put forward before 1 June 2022 were included.

In addition, we included more data sources beyond CDP and sustainability reporting to ensure an optimal coverage of the continuously changing target landscape. First, we included a selection of targets announced in news items. Companies often presented targets and ambitions in press release or news articles after their most recent annual publications. Therefore, updates for 2022 were often announced later than sustainability reports and the latest CDP responses (which became available in May of 2022). These announcements could further be divided into news sources associated to the companies directly (e.g. Nissan News) or independent sources (e.g. Reuters).

Second, the Science-Based Targets initiative (SBTi) database was included for company target collection. When targets were constructed and approved by the SBTi, i.e. defined as 'science-based target', they were documented in the SBTi database. The full database is available online, presenting scope 1 & 2 and scope 3 targets of roughly 4000 participating companies, including seven of ten car companies in this study (SBTi, 2022). For most companies these targets matched targets reported to CDP. Finally, car company targets were summarized before in IEA's latest EV outlook (IEA, 2022c) or the individual company performance assessment by Kong et al. (2021). When these analyses included new targets not yet covered by the sources above, they were added to the research.

3.2.2. Reduction target landscape and analysis

After collection, all emission reduction targets were grouped based on car company, target type, emission scopes and covered time period to explore the current target landscape. Only clear quantitative emission reduction targets were included. To be qualified as quantitative target, targets must include a base year, target year and a percentual reduction to be achieved in the indicated target year. End-of-life targets on using recycled materials in new vehicles were an exception. As these are no reduction targets, they do not require a base year: a target year and clear percentual ambition sufficed. The set of targets was divided according to the three emission scopes and the detailed supply chain categories identified in the theory section:

- Targets related to direct manufacturing and company operation were combined into the category of absolute scope 1 and 2 emissions.
- For scope 3 targets, we further divided into five main categories for upstream, downstream and logistics targets covering both:
    - Upstream-specific targets for the raw material supply chain.

  - Use phase targets (i.e. WTW emissions).
  - Downstream targets specifically for fuel supply (TTW emissions). These are generally already included in category 1, but sporadically covered separately.
  - End-of-life targets. This category only included quantitative targets on intended percentages of recycled materials in this analysis.
  - Logistics targets. This category combined both upstream and downstream logistics, as this distinction was not always clarified within the targets.
- The final category included targets to reduce total life cycle emissions or total carbon footprint. Here, we assumed all scopes were covered, including both upstream and downstream activities for scope 3 specifically.

Afterwards, reduction targets were analysed based on the division in short-term targets until 2030 and long-term targets until 2050. In addition, we estimated the covered emission scopes and coverage of the supply chain stages identified above based on the emission data provided by the car companies. Company EV sales targets were analysed separately in the downstream analysis and were thus excluded from this section.

3.3. Upstream analysis: steel and EV batteries

To explore upstream scope 3 emissions of car manufacturing further, we assessed steel and battery strategies in company reporting and literature. Steel and battery production are two crucial components in upstream car manufacturing supply chains and related upstream reduction potentials. However, because of data availability and limited coverage of upstream processes in particular, this part is exploratory in nature with a focus on a better understanding of upstream activities. Complex upstream car supply chains make a country-specific analysis for upstream impacts almost impossible.

As an alternative, we attempted to assess reduction potentials through in-depth company analysis and literature review instead. The most recent company sustainability reports were analysed based on all relevant mentions on steel and batteries. After this step, company strategies on steel and batteries found in sustainability reporting were summarized in an overview chapter with individual company highlights. A similar in-depth analysis of corporate strategies on steel and batteries had not been conducted earlier in the existing body of literature consulted for this study.

The sustainability reports from the ten car companies were considered the principal data source for this section. However, collected data also included additional data annotated or closely related to information in the sustainability reports. Examples were individually reported supplier requirements, supply chain audits or material-based strategies that were referenced in the reports. All company highlights on steel and EV batteries were later summarized in the results section. Relevant assessment criteria included:

- Overall quantity and quality of steel and EV battery coverage
- Transparency of policies, supply chains and risk assessments
- Possible company involvement in climate action initiatives related to these topics, e.g. H2 Green Steel)
- Availability and quality of corporate supplier criteria or guidelines
- Existence of quantitative reduction targets on upstream supplier emissions
- Planned implementation levels of research and material innovations, e.g. carbon-free steelmaking or solid-state batteries (SSBs)

Company results were later compared with findings from scientific literature on steel and battery reduction potentials through literature review. Quantitative estimations and possibilities of overall lightweighting in car manufacturing were explored and compared to the information given by the carmakers. In this section we focused on environmental impact data from lightweighting practices, e.g. in LCAs or comparable tools. The literature review was initiated through snowball sampling of two recent literature reviews on lightweighting by Luk et al. (2017) and Kelly & Dai (2021).

3.4. Downstream analysis: EV targets and emission model

The downstream analysis consisted of EV targets and the comparison between national and company pledges. The analysis aimed at all corporate targets and national policies advocating the sales of EVs (the sum of BEVs and PHEVs) until 2030. After target collection, national and company EV targets in the top five car markets were integrated into an Excel-based model to quantify the reduction potential of car companies and their contributions to national climate action in this decade.

Recent analysis on car manufacturing EV targets by NewClimate Institute et al. (2021) was the starting point for this analysis. This study collected corporate EV sales targets before in the period up to February 2021. With the exception of Hyundai-Kia, all companies included in this study's scope were included in this report. Furthermore, the report included an GHG emission calculation model that projected emission reductions from car companies for the EU27 + UK, China and the United States. As explained in the region selection in chapter 1, we further expanded these findings with updated data sources for these three regions and the addition of Japan and India as fourth and fifth car market. The EV target analysis and emission model characteristics are explained further in the next section.

3.4.1. EV and fuel target collection

In preparation of the model calculation, EV targets were collected from sustainability reports, previous car market analyses and additional news sources previously listed in this chapter. Similar to the reduction target analysis in section 3.2, all targets put forward before 1 June 2022 were included. Long-term targets beyond target year 2030 were not included for this specific target analysis because most companies did not announce quantitative EV targets beyond target year 2030. Furthermore, we distinguished two main types of EV targets:

- Percentual EV sales targets (expressed in the percentage of EVs in total car sales)
- Absolute EV sales targets (expressed in annual EV units sold)

We only focused on the first category of percentual targets because the average of percentual targets was later used directly in the model calculation. Absolute EV targets were only used when percentual targets were unavailable. In these cases the targeted EV sales were translated into percentual targets based on sales projections. Other target types such as cumulative sales targets or number of EV models in the company line-up were not assessed. Collected EV targets were later categorized by car company and target year. Additionally, we specified EV targets that were specifically announced for one or more of the five regions included in table 2.

The objective of the downstream analysis in this research was aimed at company and national impacts. Therefore, the collection process not only included company targets but also national targets. The analysis on national targets included two target types: EV sales targets and targets on the fuel performance of vehicles. Both target types were initially collected from IEA resources on transport policies. All targets were summarized per region in IEA's online EV Policy Explorer and EV Outlook reports of 2021 and 2022 (IEA, 2021a, 2022d, 2022c). The IEA is continuously keeping track of both target types described above. The Policy Explorer additionally distinguishes national targets based on these categories:

- The effective level of the policy or target (transnational, national or subnational)
- The included vehicle category (light-duty vs heavy-duty vehicles)
- The status of the policy or target (legislation or official target vs unofficial ambition)

Following this division, we selected (1) light-duty or passenger car policies on (2) national level which were regarded by IEA as (3) official policy. The EV Policy Explorer served as primary data source together with any additional clarification or updates published by the governments or news items. After collection, national EV targets were categorized in the same way as corporate EV targets, accounting for the relevant region and target year.

Furthermore, we collected national fuel performance standards until 2030. These values were based on ICCT calculations for passenger car standards (ICCT, 2020). For the Unites States we used updated values for a combination of light-duty vehicles and passenger cars instead (EPA, 2021). All national fuel performance targets were translated into the unit of gCO_2/km because fuel targets can further be expressed as fuel use per unit of distance, such litres of fuel per 100 km (L/100 km) or miles per gallon (mpg). EV and fuel performance targets were later used to calculate car fleet emissions in the GHG emission model.

3.4.2. GHG emission model

In the last research part a quantitative emission model was set up to estimate GHG emission reductions under the collected EV targets. The model was based on targeted EV sales shares and fuel performance targets from car companies which were compared to a reference situation with only national targets. We calculated emissions until 2030 for the total passenger car market in every region. For the US we also included light trucks (e.g. pick-up trucks and SUVs) because of their widespread use in this region and the small share of passenger cars alone. To best account for possible overlaps, we looked at the additional ambition from companies on top of current national stated policies. By using historical country data on car fleet, car sales and various key transport indicators, we estimated emissions of the car fleet until 2030 under the assumption that company EV targets presented in this report are achieved. The model consisted of two main parts. First, we determined the projected EV uptake from companies and their aggregated impact per country based on individual company market shares. In the second part we combined these results with historical car data to project emission levels in two scenarios for each of the five regions.

We retrieved an average value of EV sales in 2030 for each region from the collected EV target list. These values resulted from a combination of region-specific and overall company targets collected for 2030 specifically. Region-specific EV targets for the Europe, the US, China, Japan or India were directly used. Alternatively, we estimated these regional percentages based on company-wide EV targets when one of these markets was not specifically mentioned in EV targets. The average EV shares in company targets were multiplied with the market shares for each car company to estimate the additional effect per car company. We accounted for the most recent market shares in 2021 to estimate the aggregated impact of the companies in each of the five markets until 2030. An individual car company's market share was defined as its combined 2021 sales (including all subsidiary brands owned by the company) divided by the total passenger car sales in 2021 for that market. The estimated market shares of 100% EV companies Tesla and BYD were later added to the ten conventional car companies as well. Passenger car sales data in 2021 was retrieved from European, American and Asian domestic car associations (e.g. JADA, ACEA) and generic statistical databases for cars (e.g. CarSalesBase). We assumed that car company market shares in 2021 did not change until the end of the model in 2030.

Finally, we completed the model preparation phase by collecting all remaining parameters and prerequisite data for the calculation, such as car fleet data, regional carbon intensities of fuel or electricity, and historical EV sales. Together with the new 2030 EV values constructed in the previous step, we calculated GHG emissions for each year. Henceforth, we estimated the emissions resulting from the car company EV targets for years 2021-2030 in two separate scenarios and five regions. These scenarios predicted emission levels for the regions with and without the additional targets of the selected car manufacturing companies. The final GHG reduction potential for this study was based on the difference in emissions between the two scenarios expressed in tonnes of CO_2.

The concept of national stated policies in this analysis was based on the definitions from IEA's Stated Policy Scenario (STEPS). The STEPS is one of the global scenarios used in IEA reporting to project future energy and emission trends based on various climate action plans like NDCs. The STEPS explores current and developing policy settings per sector and country based on the available circumstances, but does not automatically assume that all ambitions are reached. It therefore has a more conservative view in comparison to other IEA scenarios such as the announced policy scenario (APS) which by definition assume all national ambitions are fully achieved. Furthermore, the IEA defines the objective of STEPS as a benchmark to assess the potential achievements of recent development in policies (IEA, 2021b, 2022a). This particular scenario was thus chosen as a realistic benchmark to best assess possible additional reductions from car manufacturing companies at this moment in time. On the one hand, it reflects the current national policies and those under development to enable comparisons with corporate targets. On the other hand, it can simultaneously reflect the differences between implemented targets and unofficial or subnational ambitions identified in the national target list, because it does not automatically assume all national policies are achieved. STEPS values were used in the first scenario. The differences between the two scenarios are further explained below.

- **Scenario 1: national stated policies**

  In the first scenario, we assumed national stated policies in the top five car markets were achieved until 2030. Therefore, we calculated GHG emissions from national EV sales targets and fuel efficiency policies represented by the STEPS values which serve as a reference of national emission levels in the first scenario. IEA projected the number of BEV, PHEVs and their sales share in the STEPS for 2025 and 2030 on the EV Data Explorer page (IEA, 2022b). We retrieved the STEPS dataset in May 2022 accompanying the publication of the 2022 EV Outlook. In scenario 1, STEPS EV projections were directly used to establish the emission levels of these EV shares per region. Most importantly, this first scenario of current national policies did not yet include the impact of company targets.

- **Scenario 2: national stated policies + additional impact from car companies**

  In the second scenario, the individual pledges of the ten selected car companies and two EV-only companies were integrated to STEPS results. We calculated the additional EV share from corporate actions and used these new EV shares instead of STEPS values. Per company, we first determined the percentual difference between the average EV share of the company and the STEPS EV share from scenario 1. This difference was then multiplied by the company's market share in 2021. The sum of all companies led to the new 2030 EV percentage used for the regions in the second scenario. Finally, this share included an additional EV bonus from Tesla and BYD. For these two companies we directly added their market shares because they have 100% EV sales. Most other parameters remained equal to scenario 1. Hence we calculated the new EV sales based on the assumptions that total car sales, car fleet and the ratio between BEV and PHEV sales did also not change from the first scenario. GHG emissions in scenario 2 were calculated in the same way as scenario 1.

After target collection and scenario creation, GHG emissions resulting from downstream EV uptake and fuel policies were estimated following the calculation steps in annex I. In addition, table 3 below shows all parameters used to set up the model for each region and summarizes differences between regions and scenarios. The region-specific data did not change with a different EV uptake between scenarios 1 and 2. The data in the first column of table 3 derived from various projections that were listed in the supplementary data files. For the future car fleet size, we extrapolated historical fleet data with annual growth rates of person-km. In addition, intermediate values between projected EV sales in 2025 or 2030 were calculated through linear interpolation. Furthermore, the average EV electricity demand and overall car lifetime did not change between scenarios nor regions. In both scenarios, PHEVs were modelled as 50% ICEV and 50% BEV to highlight them as transitional tool between ICEV and BEV powertrains. This value also reflects PHEVs operation patterns in real life, which are on average between 45% and 49% in electric mode (Plötz et al., 2022).

Table 3. Model summary including all parameters used.

Car market data (region-specific)	Scenario-specific parameters	Constants
Person-km or vehicle-km	BEV and PHEV sale shares	Car lifetime
Annual car sales and fleet size	BEV and PHEV sales	EV electricity demand
Car fleet size		
Carbon intensity of electricity		
Carbon performance of cars		
Car occupancy		

4. Results

In this section we summarize current emission inventories and the landscape analysis of collected corporate reduction targets in the first sections. Sections 3 and 4 present individual results on upstream and downstream scope 3 emissions. The final section includes the results of the model.

4.1. Emission inventory

Current emission inventories found in recent company reporting were summarized in table 4 below. These values were based on public information. All companies directly provided scope 1 and 2 emissions in their recent sustainability reports, either separately per scope or combined as total direct GHG emissions. These results clearly showed the relative low share of manufacturing emissions in scope 1 and 2 compared to the share of scope 3 emissions.

Table 4. Estimated scope 1, 2 & 3 emissions in 2020 and 2021 based on sustainability reporting (Ford, 2021; General Motors, 2021; Honda, 2022; Hyundai, 2021; Kia, 2021; Mercedes-Benz, 2022; Nissan, 2021; Renault, 2021; Stellantis, 2022; Toyota, 2022; Volkswagen, 2022). Scope 3 values for Stellantis and Ford are incomplete.

Company & emission year	**GHG emissions ($MtCO_2e$)**			**GHG emissions per car**
	Scope 1	**Scope 2**	**Scope 3**	
Toyota (2020)	1.64	3.26	341.35	48.7
Volkswagen (2021)	4.74	2.42	364.14	43.5
General Motors (2020)	1.21	3.09	259.73	29.9
Stellantis (2021)	1.64	2.23	136*	26.0
Hyundai-Kia (2020)	2.85	5.32	167.33	29.9
Honda (2021)	1.12	3.38	249.98	60.5
Ford (2020)	2.96		280*	69.0
Nissan (2020)	0.74	1.80	135.07	38.5
Renault (2020)	0.50	0.45	72.28	28.7
Mercedes-Benz (2021)	0.9		99.03	40.1

The level of scope 3 emission disclosure was different between the ten companies. Total scope 3 emissions varied across the ten companies and did not always reflect the relative position of a company and its overall sales in 2020. Table 4 sorted car companies by car sales in 2020, with Toyota as market leader and Mercedes-Benz as number ten. However, the results show that larger car companies did not automatically have more emissions than smaller ones. For example, we observed relatively high levels of scope 3 emissions from Ford, whose (incomplete) scope 3 emissions exceeded total emissions from General Motors and Honda. Similarly, Hyundai-Kia reported lower emissions than Honda and Ford despite selling 1-2 million more cars in 2020. The last column highlights these differences in emission intensity per car between the companies.

Although all ten companies provided data on scopes 1, 2 and 3, results in table 4 could not always be easily compared. First of all, reported emission years consisted of both 2020 and 2021 because six companies had not published data for 2021 before the cut-off date in mid-2022. In addition, some companies only provided partial scope 3 data or referred to additional data sources. Eight out of ten companies provided a complete estimate of scope 3 emissions in recent sustainability reports. Five of these eight reports directly included scope 3 emissions in the report. For Kia, General Motors and Renault, scope 3 data was only publicly available in additional data sources. The final two companies, Stellantis and Ford, only disclosed partial scope 3 emissions. More specifically, Stellantis' estimate of 136 Mt was based on European sales instead of total sales, and

Ford only provided the use of sold products (USP) emissions, which is the largest scope 3 category for cars. Total scope 3 emissions for these two companies likely exceed the reported values in table 4.

Furthermore, the presented scope 3 emissions did not necessarily include a separate breakdown of scope 3 subcategories defined in the GHG Protocol. For instance, some companies chose to only include the largest subcategory or used slightly different categories to break down their scope 3 emissions. This observation differed from most companies' CDP responses. Because the CDP questionnaire requires specification per emission category, all ten companies reported emission inventories including all scope 3 subcategories to CDP in 2020. This trend continued for 2021, although one company declined to participate that year (CDP, 2020, 2021). However, the results in table 4 only included public data because CDP data is confidential. In conclusion, not all companies chose to cover scope 3 emissions as extensively in their sustainability reporting as they did in CDP responses.

4.2. Landscape analysis

4.2.1. Company reduction target analysis

Following the methodology in section 3.2, 79 emission reduction targets were collected. Annex II contains the full list of corporate reduction targets from all ten car companies including target description, targeted emission reduction, base years and target years. Following aforementioned target collection criteria, table 5 only contained quantitative targets aimed at direct emission reductions with the exception of recycling targets that covered recycled materials instead. The seven collected recycling targets were included as downstream scope 3 targets for the GHG emission analysis below.

The targets are listed in table 5 per car company and targeted period. Of the 79 targets in total, 52 targets were aimed at the short term (target years 2022 – 2030), covering two-thirds of all targets. The majority of these short term targets had target year 2030. Similarly, for long term targets between 2031 and 2050 most targets had specific target year 2050. With the exception of Honda, all car companies in this study put forward one or more short term targets. Seven companies also included long-term targets, with six of them covering both short term and long term activities.

Table 5. Total collected targets and target year analysis per car company.

Car company	Short term (2022-2030)	Long term (2031-2050)	Total targets
Toyota	7	4	11
Volkswagen	7	0	7
General Motors	1	2	3
Stellantis	5	5	10
Hyundai-Kia	4	4	8
Honda	0	4	4
Ford	2	2	4
Nissan	9	6	15
Renault	13	0	13
Mercedes-Benz	4	0	4
Total	**52**	**27**	**79**

When GHG Protocol emission scopes were taken into account, targets could further be divided into scope 1+2 targets, scope 3 targets and total emission targets. From annex II we identified 27 scope 1+2 targets, 12 total emission targets for all scopes, and 37 scope 3 targets. Three targets could not be identified with certainty. In total, 49 of 79 GHG targets (62% of all targets) included scope 3 emissions, either directly in specific scope 3 targets or indirectly in reduction targets that covered all scopes. Specific scope 3 targets could be divided further into upstream and downstream impacts. Nearly all scope 3 targets were focused on downstream emissions (see table 6). Of the 34 scope 3 targets, only one was identified as upstream-specific target, compared to 32 scope 3 downstream targets. When we added life cycle targets to the analysis, total upstream coverage increased because most life cycle targets included both upstream and downstream emissions.

Table 6. Upstream and downstream coverage of collected targets for specific targets on scope 3 emissions (top) and the combination of scope 3 & life cycle targets (bottom).

Coverage of specific scope 3 targets	**Upstream**	**Downstream**	**Upstream + downstream**	**Uncertain**
Number of targets (N=37)	1	32	3	1
Coverage	3%	86%	8%	3%

Coverage of scope 3 + life cycle targets	**Upstream**	**Downstream**	**Upstream + downstream**	**Uncertain**
Number of targets (N=49)	1	34	12	2
Coverage	2%	69%	24%	4%

However, the overall lack of upstream supply chain targets did not change. Of the 79 targets, there was still only one target identified as upstream scope 3 specifically. This meant that with one exception, upstream scope 3 emissions were only targeted in combination with downstream impacts, either through life cycle emission targets covering all scopes or through logistics targets in which it was not possible to distinguish upstream and downstream effects. Table 7 below shows the difference between specific upstream and downstream emission coverage and the lack of upstream targets across all categories. In conclusion, the vast majority of targets that cover upstream scope 3 emissions was not upstream-specific but mostly included a combination of upstream and downstream emissions (the row upstream + downstream in table 7). As a result, the only upstream-specific target identified in this analysis covered only 1-3% of total targets. Furthermore, the total upstream coverage was consistently lower than the total downstream coverage.

Table 7. Summary of percentual target coverage per category. For the second column, uncertain and scope 1+2 targets were subtracted from the total. For the third column, life cycle targets were subtracted, resulting in scope 3 targets only. Furthermore, upstream + downstream targets (row 3) were included in both upstream and downstream estimates, which is why the sum of the final two rows can exceed 100%.

	N=79	*N=49*	*N=37*
Category	**All targets**	**All scope 3 incl.**	**Specific scope 3**
Upstream only	1%	2%	3%
Downstream only	43%	67%	86%
Upstream + downstream	15%	26%	8%
Uncertain	6%	4%	3%
Scope 1 + 2	*34%*		
Upstream total	16%	28%	12%
Downstream total	58%	93%	94%

4.2.2. Target type and emission coverage

After the count analysis of the target landscape, we analysed reduction targets of the ten companies per supply chain category in table 8 below. Categorization was based on the seven supply chain categories identified in the method section, i.e. production (scope 1+2) targets, life cycle (scope 1+2+3) targets, and five different types of specific scope 3 targets such as recycling and TTW. As of June 2022, all car manufacturing companies have set a minimum of one target aimed at scope 3 GHG emissions. Each company is currently targeting the largest emission category of WTW emissions. Likewise, direct car manufacturing emissions (scope 1&2) are targeted by nine companies. For other scope 3 activities such as logistics, end-of-life or upstream supply chains, we observed a more diverse level of emission coverage in table 8.

Table 8. Company emission reduction target coverage across categories in car supply chains.

Company	Logistics (up + down)	Upstream supply chain	Production (Scope 1 + 2)	Fuel supply in use (TTW)	Use of sold products (WTW)	Recycling	Life cycle (all scopes)
Toyota	X		X	X	X		X
Volkswagen			X	(X)	X		X
Gen. Motors			X	(X)	X	X	
Stellantis	X		X	X	X		X
Hyundai-Kia			X	(X)	X		
Honda				(X)	X	X	X
Ford			X	(X)	X	X	
Renault	X	X	X	(X)	X	X	X
Nissan	X		X	(X)	X	X	X
Mercedes	X		X	(X)	X	X	

Table 8 further highlights the noticeable lack of upstream supply chain targets in quantitative emission reduction targets. The first individual company that stood out from this analysis is Renault, which was the only company with a specific reduction target for the upstream supply chain. This resulted in Renault being the only company to include targets for all categories in table 8. On the contrary, Hyundai-Kia stood out by covering the least categories. This company's only USP target was specific for the Kia brand since Hyundai only targeted production emissions. Moreover, Hyundai-Kia targets for either logistics, recycling or the complete life cycle were still absent. Finally, Honda was the only company without specific targets for direct scope 1 and 2 emissions.

For the use phase, we assumed that fuel supply and fuel production are automatically covered by USP targets, indicated with "(X)" in table 8. Stellantis and Toyota were the only companies that included targets for well-to-wheel and tank-to-wheel emissions separately. All recycling targets referred to the inclusion of recycled materials in new vehicles, except for Ford's target which was specifically related to plastics in new vehicles. Therefore, this target may have a reduced potential in comparison with the other targets in this category.

The results above were combined with reported supply chain emissions for passenger cars to estimate the percentual emission coverage from collected targets. This estimate was based on current car manufacturer data on GHG emissions per vehicle. Mercedes-Benz provided an example of vehicle emissions for the categories in table 8 in their 2022 sustainability report (figure 6).

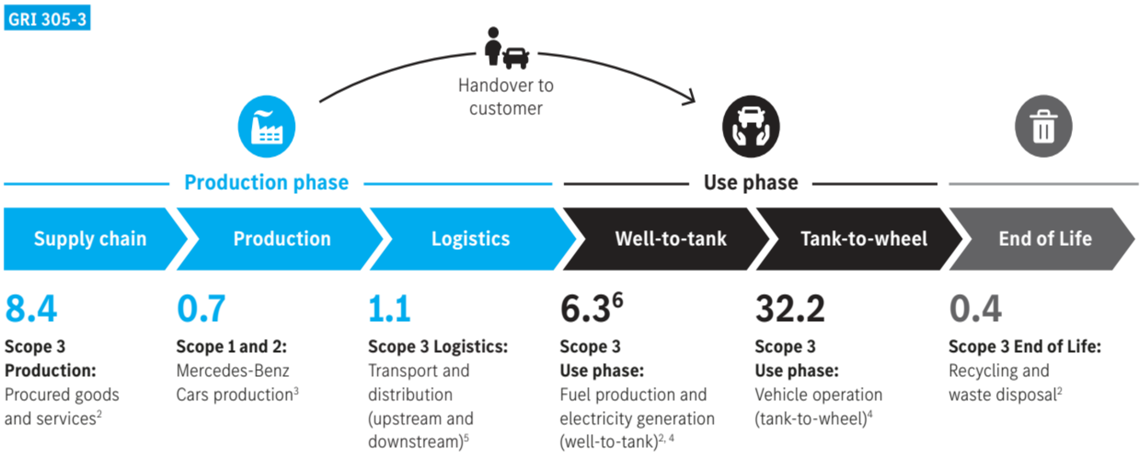


Figure 6. Vehicle emissions in tCO_2/vehicle for Mercedes-Benz cars in 2021 (Mercedes-Benz, 2022).

Similar breakdowns of GHG emissions per category were available in sustainability reports from Renault, Stellantis and Volkswagen (Mercedes-Benz, 2021, 2022; PSA, 2021; Renault, 2021; Stellantis, 2022; Stephan et al., 2019). Estimates from the remaining six companies could not be found in the selected reports for this paper. Despite differences in absolute emissions per brand and reporting year, the emission coverage per category as percentage of total car emissions did not significantly change between the four reports included. When we assume that the average of Volkswagen, Stellantis and Renault cars represent the average of all ten car companies, a first estimation of target emission coverage can be made. The results of this calculation step were added to table 8, creating table 9 below. These car company data show that on average, the use phase (fuel production and fuel supply) causes 81% of total GHG emissions, followed by the upstream supply chain causing 15% of emissions. Recycling, logistics and manufacturing activities all have a minimal impact of 1% - 3% each.

Table 9. Overview of emission shares per targeted category. Percentages in row 2 reflect averages of car data derived from selected company estimates.

Category	**Logistics**	**Supply chain**	**Production**	**Use: fuel + operation**	**Recycling**	**Total coverage**
% of emissions	**1%**	**15%**	**1%**	**81%**	**2%**	**100%**
Toyota	X		X	X		**83%**
Volkswagen			X	X		**82%**
Gen. Motors			X	X	X	**84%**
Stellantis	X		X	X		**83%**
Hyundai-Kia			X	X		**82%**
Honda				X	X	**82%**
Ford			X	X	X	**84%**
Renault	X	X	X	X	X	**100%**
Nissan	X		X	X	X	**85%**
Mercedes	X		X	X	X	**85%**

The last column of table 9 calculated the maximum amount of GHG emissions covered by at least one corporate target. From a total emission perspective, individual differences between percentual emission coverages were limited because all companies cover the use phase, which has the largest share of life cycle emissions by a large margin. Differences were caused by the smaller scope 3 categories instead,. For example, Mercedes-Benz only covered an additional 4% of GHG emissions compared to Hyundai-Kia who did not cover logistics and recycling. Based on this analysis, nine out of ten car manufacturing companies target activities that cover between 80% and 90% of total emissions. Renault is the only exception, theoretically covering all of its emissions. These percentages do not necessarily reflect the quality and quantitative ambition of individual targets. However, the absence of specific targets for upstream supply chains, the second highest emission source, leaves 15% of emissions potentially uncovered for nearly all large car companies.

4.3. Upstream results

In this section the possibilities for reducing upstream emissions in car manufacturing are explored further. The reduction target analysis from car company targets showed a limited upstream emission coverage in the current target landscape. As a result, quantifying an upstream reduction potential based on these targets was not yet possible. This section analysed company sustainability reporting and literature estimations of potential reductions in the car sector instead. Highlights of current and future policies on steel and batteries have been summarized in the sections below. More extensive results of these in-depth company assessments on steel and EV batteries can be found in annex V, where strengths and weaknesses have been added to highlight differences between company strategies. The final section includes literature review findings on vehicle lightweighting. Accompanying the expected rise of battery and steel demand argued by Deetman (2021), we assess to what extent corporate strategies tackle new challenges occurring in car supply chains, most notably material alternatives for steel substitution and improved EV battery supply chains needed to fill the targeted rise of electric mobility.

4.3.1. Steel analysis

The ten car companies analysed in this study included limited levels of overall steel reporting in their sustainability reports. First of all, only one report exceeded more than twenty mentions on steel. Moreover, Renault and Toyota entirely omitted any steel coverage in their most recent edition. Even when information on steel was included in sustainability reporting, these mentions did not necessarily include practical examples or policy implementations that we deemed relevant for this analysis. Examples of relevant steel mentions included information on the company's current steel recycling practices, overall steel use data or any ambitions to reduce steel in specific car components or model line-up. The companies with the most steel mentions such as Mercedes-Benz and Nissan generally also included the most relevant mentions on steel.

Due to the general lack of steel-specific strategies in sustainability reports, we later expanded this section by including supplier requirements and strategies of other raw materials beside steel. We did this to analyse the car companies' level of responsibility for targeting upstream scope 3 emissions because most of them had already neglected this part in emission reduction targets. For company strategies on raw materials we focused on the current level of raw material sourcing and risk assessment studies. To investigate climate action for the car company suppliers, we valued the companies' supplier requirements and the possible development of supplier targets to decrease emissions within these supply chains.

In the context of this study's main objective, overall transparency was one of the key factors to estimate scope 3 emission coverage. Because the methods in this section were already based on information from public reports, we investigated whether supplier information was also public. On the one hand, all car companies openly disclosed supplier requirements in online sources. On the other hand, the quality and content of these requirements varied between companies. In some cases, the available requirements simply consisted of basic principles without additional explanation. Other companies distinguished separate requirements per supplier type or explicitly required suppliers to report and target their scope 3 emissions to the company.

Unlike supplier requirements, few companies disclosed their steel demand, steel use or specific steel emission data. Sustainability reports often contained generic sections on raw material and circular economy policies, but steel was only occasionally covered in these chapters. Volkswagen provided an example of this trend. Various waste, water, recycling were included in Volkswagen's circular economy chapter, even including a small section on aluminium initiatives and recycling, but steel was only mentioned once. The minimal coverage of steel compared to other indicators also occurred in the companies' data provision. Most sustainability reports contained separate appendices with environmental data. We observed that steel indicators like total tons of used steel did not appear in many of these extensive data appendices, whereas similar data on total water, waste or energy use was included. In total we collected steel use data from three out of ten companies. This further complicated this research's assessment of any quantitative reduction potential based on public data. When comparing steel coverage and supplier requirements, companies with relatively high and strong coverage of steel strategies in their reports often covered supplier requirements less extensively and vice versa. A clear example was Ford, who presented detailed supplier requirements for scope 3 and material sourcing but no steel policies or data. Mercedes-Benz showed the exact opposite, with very basic supplier requirements and steel risk assessment coverage despite being one of the frontrunners on steel initiatives and innovations.

To conclude this section we briefly assessed reduction target possibilities. The combination of low data transparency and limited steel coverage in most reports naturally led to few examples of steel emission reduction through targets and innovations. The only example until this point was the one identified upstream target on Renault's parts and material supply chain. Apart from that target, Toyota and Honda were the only companies with an annual and quantitative reduction target aimed at suppliers specifically. Toyota targets a reduction of 4% in emissions from suppliers in 2022, while Honda aims for an annual 3% supplier reduction as part of a long term plan towards 2050. For steel specifically, no targets have yet been developed. However, we found four companies with involvement in a number of steel initiatives. Volkswagen, Hyundai-Kia, General Motors and Mercedes-Benz are part of various initiatives aimed at producing less emission-intensive steel. Hyundai-Kia's efforts are mostly through its subsidiary companies, because Hyundai Steel is in the Responsible Steel Initiative and parts supplier Hyundai Mobis recently constructed SBTi-approved emission reduction targets. During 2022 General Motors and Volkswagen partnered with Nucor and Salzgitter AG, respectively, for the production of zero-carbon steel. Mercedes-Benz had the strongest position in this area. Not only did this company partner with two companies producing lower carbon-intensive steel and two steel initiatives, it also added a clear time horizon to its future steel strategies by targeting H2 Green Steel use in 2025.

4.3.2. Battery analysis

In general, companies provided more information and strategies on batteries compared to steel in the previous section. The quantity of battery mentions in sustainability reporting was significantly higher than the number of steel mentions, averaging around 80 mentions per report. Although this value also included less relevant mentions for this research (e.g. use of "battery" as part of "battery electric vehicle"), the quantitative differences between basic battery and steel coverage on company level was remarkable. For example, the two sustainability reports without any mentions on steel both included over 50 mentions on batteries. This high coverage level allowed for a more thorough analysis of corporate ambitions because companies reported more examples of specific battery innovations or planned strategies. Additional reports or press releases on batteries often included even more information.

One commonly mentioned theme was battery recycling. This was often combined with larger recycling or energy recovering systems. Examples were Hyundai-Kia's energy storage system or Renault's and Nissan's technologies to enable EVs to return energy to the electricity grid for uses elsewhere. These battery strategies were also often combined with larger projects such as research hubs or new EV production facilities. Unlike steel strategies, battery strategies were integrated better in the car companies' vehicle line-ups as well. Many companies had personalized features in their battery strategies. This led to more unique technologies, e.g. General Motors' Ultium battery platform or implementation of most recent innovations in the recently launched Mercedes-Benz electric EQ series.

Most importantly, this section also led to more quantitative estimations on emission reductions and more clarity on planned strategies. This was partly caused by the clearer time horizons linked to battery strategies. Car companies were able to set target years for new EV facilities or adoption of new battery types in vehicles. Various battery facilities were planned in the short-term to increase the scale of EV capacity in the coming years. This will be necessary if companies wish to reach their EV sales targets in 2030 that we cover in the downstream part of the research. When focusing on innovative battery types, we observed that most companies have announced plans of replacing conservative lithium-ion batteries (LIB) with solid-state batteries (SSB) which would reduce climate impacts. The time path and provided level of detail on these ambitions differed per company, but many targets are short term (before 2030). Stellantis and Nissan presented clear targets for replacing lithium-based types with solid-state alternatives before 2026 and 2027, respectively. In addition, some car companies without such clear-cut targets like Honda, Ford and Mercedes-Benz still pledged to heavily invest in SSB research and development in this decade. In most future visions from the included companies, SSBs are clearly seen as the dominant battery technology. However, Toyota stood out through planned continuation of conservative nickel-based batteries rather than future investment into SSB options. This choice aligns with Toyota's corporate strategy and EV targets, as they keep relying on HEVs for electrification options instead of BEVs or even PHEVs.

Nonetheless, not all battery strategies were specifically aimed at this report's objective of investigating emission reductions. Company ambitions also covered additional aspects such as battery costs and vehicle safety. Car companies thus heavily plan to invest in covering EV disadvantages from a consumer side, for instance by offering maintenance services, improve driving ranges or facilitate charging infrastructure. In certain reports, ambitions for batteries were also expressed in monetary values rather than targeted reduction or innovations. While the amount of invested funds gave an indication of the total scale of ambitions, their targeted effect on emission reduction was not as clear in these cases.

In summary, estimating specific upstream emission reduction potentials from batteries remained challenging, albeit to a lesser extent than steel strategies. Battery strategies generally contained more details and were integrated better with other ambitions than steel strategies. The battery analysis also yielded more key environmental data that would facilitate the process of estimating reduction potentials, such as current recycling rates, audits from key battery production materials like nickel, cobalt or lithium or LCA results of BEV models. However, the level of detail provided in sustainability reports was different between individual car companies.

4.3.3. Lightweighting literature review

Finally, we attempted to give an indication of upstream GHG impacts by discussing results of literature instead of quantitative reduction potentials. In this chapter we focused on emission reductions resulting from lightweighting which can be combined with individual company results on steel and batteries. Literature review on the existing corpus of peer-reviewed literature on lightweighting has been conducted by overview studies Kelly & Dai (2021) and Luk et al. (2017).

Automotive lightweighting studies have been around since 1995. Despite many successful lightweighting measures in vehicles, the average overall weight of a standard vehicle has not decreased over time (Kelly & Dai, 2021). On the contrary, in many cases overall vehicle weight has actually increased (Kawajiri et al., 2020). This does not necessarily reflect the car performance, however. For instance, there is a clear trend of American cars with lower use of regular steel and higher use of common alternatives (e.g. higher strength steel options or aluminium) from 1995 onwards (Kawajiri et al., 2020). The term lightweighting is used in the context of this paper to replace conventional steel and iron casting with other materials, ultimately reducing not only weight but GHG emissions over the life cycle. The most mentioned options for replacing conventional steel in automotive use are (Luk et al., 2017):

- Strengthened steel routes, e.g.
  - High strength steel (HSS)
  - Advanced High Strength Steel (AHSS)
- Aluminium
- Polymer options, most notably:
  - Carbon fibre reinforced polymer
  - Glass fibre reinforced polymer
- Magnesium

One important metric to assess the lightweighting effectiveness of steel substitutes is the materials substitution ratio (MSR), which indicates the weight of the substitute needed to fully replace 1 kg of conventional steel, ranging from 0 – 1. Naturally, AHSS and HSS both have relatively high MSR values since they have similar properties to conventional steel, typically 0.8 – 0.9 on average. As lightweight metals, aluminium and magnesium have medium range MSRs. Finally, while glass fibre MSR values typically range between those of HSS and aluminium, carbon fibre has the lowest average MSR of 0.3 (Kelly & Dai, 2021; Luk et al., 2017). However, as observed in these analyses and figure 7 below, the range of minimum and maximum estimates per material can differ significantly.

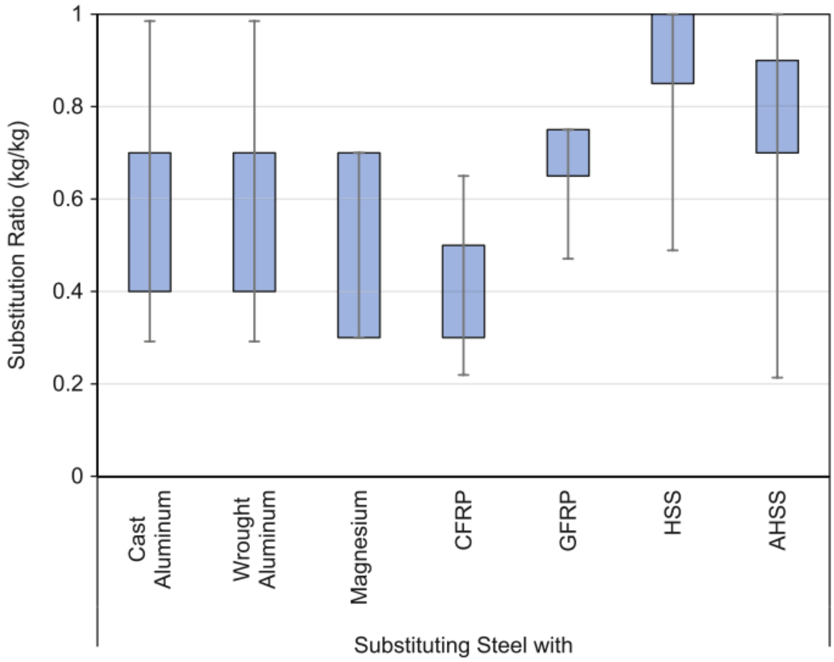


Figure 7. Material substitution ratio range for various materials (retrieved from Kelly & Dai, 2021). CFRP and GFRP refer to carbon fibre and glass fibre polymers.

The carbon intensity and energy consumption per kg of material of these options shows an opposite relationship to the MSR. Conventional steel has the lowest carbon intensity, following by higher-strength steel, aluminium, fibres and finally magnesium (Kawajiri et al., 2020). Due to its high carbon intensity and minimal interest from selected car companies in this research, magnesium is not analysed further as a functional lightweighting option here.

Aluminium is the most used metal after steel in car production and has often been used as replacement for steel (Kong et al., 2021). Specific possibilities of aluminium-intensive lightweighting are described by Modaresi et al. (2014). Furthermore, strategies of aluminium, most notable recycling options, were mentioned relatively often within corporate sustainability reporting. Kong et al. also state that BEVs already include 45% more aluminium on than ICE cars because of the specific batteries. This indicates that aluminium lightweighting is on the rise, especially in the context of EVs.

Most studies on lightweighting focus on GHG emissions. Because the production emissions of many cars with lightweighting alternatives are higher compared to standard car models, a net reduction of emissions only follows during a certain period in the car's use. The breakeven point where the emissions of both versions are equal is a suitable tool for estimating the effectiveness of lightweighting strategies. This metric is usually expressed in a number of km driven, indicating that the additional distance driven after that point in a lightweighting vehicle leads to a net reduction. Overall, most, but not all, studies concluded that a weight reduction leads to an increase in fuel efficiency. Exact quantification of lightweighting effects varies and is heavily dependent on the assumption set used in a study's calculations. Generally, this is estimated by assuming a fixed value of weight reduction in turn leads to another fixed value of fuel efficiency improvement. For instance, Kawajiri et al. (2020) included six different models with varying ranges of estimated reductions. In a few cases, weight reduction and benefits are so large that they immediately pose a life cycle benefit, but those are mostly exceptions (Luk et al., 2017). In terms of companies assessed in this analysis, both General Motors and Ford have presented or funded scientific comparative studies of lightweight models within their vehicle line-up. In both situations a significant reduction of weight and GHG emissions was achieved, with 16.7% and 23.5% mass reductions, respectively (Bushi, 2014; Bushi et al., 2018).

However, lightweighting applications must also be assessed based on EV characteristics. An important finding on achieving fuel savings through lightweighting practices was found by Luk et al.: the maximum fuel savings increase with lower powertrain efficiencies. Between the three main powertrains (ICEV, PHEV/HEV, BEV), hybrids are able to use (gasoline) fuel more efficiently than conventional ICEVs. Furthermore, the efficiency of the electric motor and battery charging efficiency of BEVs is higher than an ICE's thermodynamic efficiency. Therefore, maximum fuel savings for BEVs are the lowest of the three because of the higher powertrain efficiency and lower kinetic energy demand (Kim & Wallington, 2016). This does not mean BEVs cannot achieve lower GHG emissions, because these are still heavily dependent on the characteristics of the fuel or electricity mix when considering BEVs. As fuel efficiency improves, the additional emission reduction effect from lightweighting in particular diminishes. This rebound effect is important to take in, also considering the timing of lightweight implementation: their effect might be lowered because of efficiency (see for a quantification e.g. Modaresi et al. (2014)). Moreover, the amount needed to offset a car's production emissions will increase when the fuel efficiency increases, meaning only when the GHG emission intensity of lightweighting materials increases faster than the fuel efficiency, a net effect takes place (Kawajiri et al., 2020).

Therefore, taking the increased costs and the outliers that did not results in initial reductions from lightweighting LCAs into account, lightweighting does not provide a silver-bullet solution. This measure is ideally combined with other solutions for EVs in particular. However, based on the other results from this study, company transparency on lightweighting practices – or any upstream strategies at all – is insufficient. The minimal coverage and inclusion of particularly steel in many sustainability reports are missed opportunities to further develop reduction targets for upstream supply chain emissions. The first mentions about reduction measures such as lower carbon-intensive steelmaking and SSB innovations have been included in recent sustainability reports. We argue that car companies may benefit from bridging the current gap between literature estimates and the companies' emission reporting and target setting if these measures would also be combined with the included examples of practical lightweighting opportunities.

4.4. Downstream results

This section summarizes downstream targets and the subsequent model calculation. Collected company and national targets are presented in separate result sections. For companies we further include the market share analysis based on 2021 sales. Similar to upstream results on steel and batteries, detailed results of collected targets can be found in the annexes. Afterwards, we present the emission reductions that we found from modelling EV targets for the five regions included in this report.

4.4.1. Company EV sales targets

Collected company EV targets were listed in annex III. All car companies presented multiple EV sales targets until the cut-off date of 1 June 2022. The many new and updated EV targets highlighted the rapidly changing market conditions for the car manufacturing sector. Nearly all car companies presented updated targets throughout 2021 and 2022 that improved earlier updates. The publication of most sustainability reports in March and April 2022 had already resulted in a number of improved targets included in the analysis. However, some companies presented even more targets and future EV visions in the period that followed. Car companies raised their EV ambitions multiple times throughout the research period in the most exceptional cases.

In the EV target analysis we focused on specific targets for the top five car markets. Companies typically did not target all of these regions, but most companies included at least one region-specific target. The majority included targets for Europe, China or the US, including the Asian-based companies like Hyundai-Kia and Toyota. Different trends occurred in Japan and India. Japan was almost exclusively covered by targets from domestic brands Honda and Nissan. In addition, car companies did not seem to prioritize specific targets for India's car market. Stellantis was the first car company to target India individually in its latest EV strategy. Other noteworthy observations resulted from Renault and Mercedes-Benz. Renault was the only company whose targets were initially focused on only one region. Renault presented European targets only, which was naturally driven by the company selling 91% of its top five car market sales in that particular region. The company recently announced that their previous 90% EV target for Europe became a company-wide target, which resulted in the first estimations for other regions. For Mercedes-Benz, we noticed an opposite pattern. Instead of distinguishing per market, this company aimed at one main ambition of reaching all-electric drive at the end of the decade. As a result, Mercedes-Benz was the only company who pledged 100% electrification in all regions for 2030.

The combination of generic and market-specific target resulted in the values shown in table 10 below. These results summarized the averages of collected targets per region. All values represent EV sales shares aimed at target year 2030. Table 10 values were estimated based on generic targets for regions without a company target. The only exception was Hyundai-Kia, who required a more extensive calculation because of the two separate brands that individually reported targets. Hyundai-Kia's values in table 10 resulted from combining both brands. Here we accounted for the market shares within the car company, which was slightly higher for Hyundai than for Kia (56% and 44% of projected 2030 sales, respectively).

Furthermore, we deliberately left out the few cases without any car sales in one of the five markets. This was limited to General Motors outside of the US and China and Renault in the US. Stellantis was the only company that presented regional targets for all five markets. For comparison, the final row of table 10 includes STEPS values used in the first model scenario. As such, the table contains an overview of the average company EV shares and how they compare to projected STEPS shares in the reference scenario.

Table 10: Average targeted EV shares for target year 2030 per company and region. Cells in green were directly presented by companies, white cells were estimated based on averages or EV targets without a regional scope. Red cells indicate excluded markets.

	Europe	**USA**	**China**	**Japan**	**India**	**Generic**
Ford	100%	50%	50%	50%	50%	50%
General Motors		40%	95%			70%
Honda	40%	40%	40%	20%	40%	40%
Hyundai-Kia	73%	67%	54%	43%	43%	50%
Mercedes-Benz	100%	100%	100%	100%	100%	100%
Nissan	75%	40%	40%	55%	45%	50%
Renault	100%		90%	90%	90%	90%
Stellantis	100%	50%	60%	50%	50%	
Toyota	49%	49%	49%	49%	49%	49%
Volkswagen	70%	50%	50%	50%	50%	50%
STEPS projection	38%	21%	44%	20%	12%	

The collected company EV targets evidently indicated how companies targeted higher EV shares for 2030 than the projection under the STEPS estimates. The only exceptions were found in Honda's targets for China and Japan, and Nissan's target in China. However, the values in table 10 did not yet account for the market shares of these ten car companies in the regions. The market share results are summarized in table 11. Individual company market shares of the selected car companies were highest in Europe, the US and Japan, where nine out of ten companies are headquartered. The ten car companies dominate large parts of European, American and Japanese markets with more than 75% of total car sales. In China and India, the combined market share was slightly lower for these car companies. This was partly caused by excluding large car companies that are mostly active in these countries, such as Mahindra & Mahindra in India and Changan in China. Even without major Indian and Chinese brands, the top ten global car companies in this research covered more than half of Chinese car sales and more than one third of Indian sales in 2021.

Table 11. Car company 2021 market shares in key markets. Market shares were defined as the total sales from a company's subsidiary brands divided by total car sales in 2021.

Car company	Europe	USA	China	Japan	India
Ford	4.51%	12.66%	1.59%	0.02%	1.18%
General Motors	0.00%	15.39%	11.24%	0.00%	0.00%
Honda	0.57%	10.16%	7.31%	14.67%	2.93%
Hyundai-Kia	8.71%	10.08%	2.44%	0.01%	22.67%
Mercedes-Benz	5.70%	1.91%	2.86%	1.41%	0.35%
Nissan	2.12%	6.78%	5.19%	10.04%	1.17%
Renault	9.49%	0.00%	0.04%	0.21%	3.24%
Stellantis	20.60%	12.30%	0.54%	1.30%	0.37%
Toyota	6.43%	15.67%	7.85%	46.38%	4.03%
Volkswagen	24.90%	4.47%	14.43%	1.78%	1.51%
Share top 10	83.03%	89.42%	53.50%	75.82%	37.43%
Others	16.97%	10.58%	46.50%	24.18%	62.57%

4.4.2. National EV sales and fuel performance targets

National targets on EV shares until 2030 included fewer updates than company results in the previous section. Despite a number of subnational targets on provinces or cities, only four EV targets were identified as official national target based on IEA's EV Policy Explorer (IEA, 2021a). The full list of EV targets from these regions before 1 June 2022 has been listed in annex IV. In addition, IEA's EV Policy Explorer logged current national fuel performance targets next to EV targets. These fuel targets were added to the downstream analysis. The targets were later added to both scenarios of the model and used for emission calculations. Recent developments in EV targets and fuel performance for each of the regions are briefly covered below.

The European Union did not publish many new EV updates in recent years. EU-wide car targets were already largely in place before 2021. The only new ambition included a recent European Commission proposal aimed at exclusively selling EVs after 2035. The same measure requires a 55% reduction for passenger car emissions relative to 1990 levels. While this is not an EV sales share target for 2030, this measure would further stimulate Europe's EV transition if approved. Furthermore, official fuel performance targets for the EU were put forward in 2019, targeting 95 gCO_2/km for target year 2020. The EU will tighten these values further in this decade, targeting an average fuel performance of 81 g CO_2/km in 2025 and 60 g CO_2/km in 2030. If the European

Commission proposal is accepted, this trajectory can be continued until 0 gCO_2/km in 2035 where ICEVs will no longer be sold.

China has also kept most of its EV targets, but many subnational EV ambitions were added in 2022. The country aims at 20% EV sales in 2025 and 50% in 2030, of which 95% must be covered by BEVs. However, the 2025 target has been lowered from a proposed 25% to the current value of 20%. In the long term China targets a completely electrified car market in 2035. This would translate to 50% covered by BEVs and PHEVs when we excluded the share of HEVs. The most important Chinese update contained a 40% EV ambition for 2030 reported by various news items in 2022. Following IEA's standards, this is not defined as official target, meaning that China only has an official national EV target for 2025. Nevertheless, the STEPS projections suggest that IEA expects a 44% EV share in 2030 which would lead to the country all surpassing 40% EVs in 2030 even under current measures. Similar to the EU, China extends national fuel efficiency targets from target year 2020 towards 2025 and 2030. In 2020 the fuel standard was based on 5 litres of fuel per 100 km driven which was the equivalent of 117 gCO_2/km (IEA, 2021a). China currently has an official fuel efficiency target of 4 L/100km for 2025 with a possible extension towards 3.2 L/100 km until 2030 (NewClimate Institute et al., 2021). This would equate to 20% reduction of 2020 levels in 2025 and 36% in 2030, respectively.

The United States was still behind the EU's and China's EV policies and targets, but presented one ambitious target to accelerate its EV uptake. The US greatly improved possible EV uptake with the first federal EV target signed by president Biden in an Executive Order in August of 2021. The targeted 50% EV share would significantly exceed previous estimations and the latest STEPS value of 21%. This measure also paved the way for development of new fuel efficiency standards after 2027 that would add to current standards up to 2026. The United States had not announced any federal targets before 2021. On state-level, New York and California had set the first official targets, aiming at 100% EV sales in 2035. Washington and Massachusetts have adopted these ambitions but these are no official targets yet. Although the new federal ambition of 50% EV in 2030 is no official legislation (and therefore excluded by IEA), this announcement clarified USA's EV ambitions on national level and a long-term vision towards target year 2035 for the very first time. The country has annual fuel performance targets for target years 2022-2026 that have recently been revised as well. The average value for standards for passenger cars and light trucks was used as an estimation for the carbon performance of light-duty vehicles in the model calculations. Under the latest regulations, this fuel performance target is 161 gCO_2/mile or roughly 100 gCO_2/km in 2026.

Like its main car company Toyota, Japan heavily relied on hybrids in future EV strategies. Japan's official EV target aimed at 20-30% EVs in 2030. This target was only presented as a range instead of one clear percentage. For the longer term, the country targets 100% of electrified vehicles in 2035. However, details on this ambition were not given, making it difficult to estimate the individual shares of BEVs, PHEVs and HEVs within this value. In addition, the reduction potential of 100% electrified vehicles is debatable for this country, considering that 98% of current electrified vehicles consist of HEVs. Because this ambition did not specify plans for vehicle types, BEVs and PHEVs may still cover a relatively low share of these electrified vehicles in favour of HEVs. Furthermore, Japan has a fuel performance target which is expressed as 25.4 km/L for 2030 and an emission reduction of 32.4% compared to 2016 emission. The ICCT estimates Japan's fuel target for 2030 at 73.5 gCO2/km for 2030 (ICCT, 2020).

India has set an ambition of 30% EV sales share target in light-duty vehicles for 2030. This ambition was formulated in 2019. An official national target does not exist yet. All new EV ambitions presented in 2021 and 2022 included subnational targets for individual Indian states. Moreover, targets often included other vehicle types such as two or three-wheelers, resulting in lower effects from passenger cars in the electric fleet. These low subnational values challenge India's national EV ambition of 30% in 2030. Current EV uptake must rapidly increase to reach this ambition and to avoid the STEPS projection of only 12% EV sales in 2030. India also had the least amount of fuel targets across the five regions. The country has still only implemented a short term target of 113 g CO_2/km in 2022 and did not yet present national fuel policies for the years thereafter.

Finally, the Electric Vehicles Initiative (EVI) may add an additional EV benchmark for these five regions. The EVI is an IEA-coordinated collaboration between companies and countries to increase global EV uptake. The EV30@30 campaign aims for 30% of global EV sales in 2030 (IEA, 2022c). China, India, Japan and five EU members participate in this initiative. This global benchmark further stimulates national EV shares of its individual members. Therefore, the EVI can serve as additional policy tool for Japan and India in particular, as these countries do not independently reach 30% EVs in 2030 under STEPS projections.

4.4.3. GHG emission model results

In the model calculation we combined all downstream results presented in the section above. The EV shares and car sales in 2030 in both scenarios are summarized in table 12. The EV shares in the second scenario resulted from the average 2030 company EV targets, the market share analysis and the model calculations in annex I. The individual EV targets of Tesla and BYD were already integrated into table 12 EV shares. Tesla and BYD added an additional EV share in the range of 0-6% to the ten company averages across the five regions. For India and Japan, this bonus was negligible (<0.1%) as both EV companies had very low Indian and Japanese sales in 2021. Tesla's effect in the European and American car markets resulted in 1.5% and 2% EV bonus for these regions. Finally, the largest EV bonus of 5.7% occurred in the scenarios for China. The difference between China and the other leading EV markets can be explained by the inclusion of BYD, whose current EV sales are almost exclusively aimed at China.

In all regions, the IEA STEPS values combined with the aggregate of company EV targets in the second scenario surpassed the estimations based on the STEPS alone. Moreover, projected EV shares and sales doubled for the EU27+UK, Japan and India after inclusion of company targets. The total amount of EVs for these five regions equated to 37 million sales in 2030 compared to 22 million sales under the STEPS projections. Although we estimated the highest share of EV shares for the EU27 and the UK, China will remain the global leader of electric mobility in 2030.

Table 12. Model input per region. EV shares in scenario 2 resulted from the company EV target analysis and the EV bonus from Tesla and BYD. Furthermore, we assume an equal amount of total car sales in both scenarios.

Region	Scenario	EV share in 2030	Total EV Sales 2030	Total car sales in 2030
EU27 + UK	1. STEPS	38%	6,572,890	17,297,080
	2. STEPS + car companies	77%	13,317,088	
USA	1. STEPS	21%	3,070,410	14,621,000
	2. STEPS + car companies	38%	5,248,097	
China	1. STEPS	44%	11,131,800	25,299,545
	2. STEPS + car companies	63%	15,870,756	
Japan	1. STEPS	20%	736,013	3,680,066
	2. STEPS + car companies	39%	1,446,649	
India	1. STEPS	12%	684,000	5,700,000
	2. STEPS + car companies	26%	1,463,545	

To conclude this section we present model results and compare across scenarios and regions. GHG emission outcomes of the model have been summarized in table 13. For all regions, the GHG emission level was lower in the second scenario. However, the size of the total emission reductions varied between regions. Individual results per region are analysed in the section below.

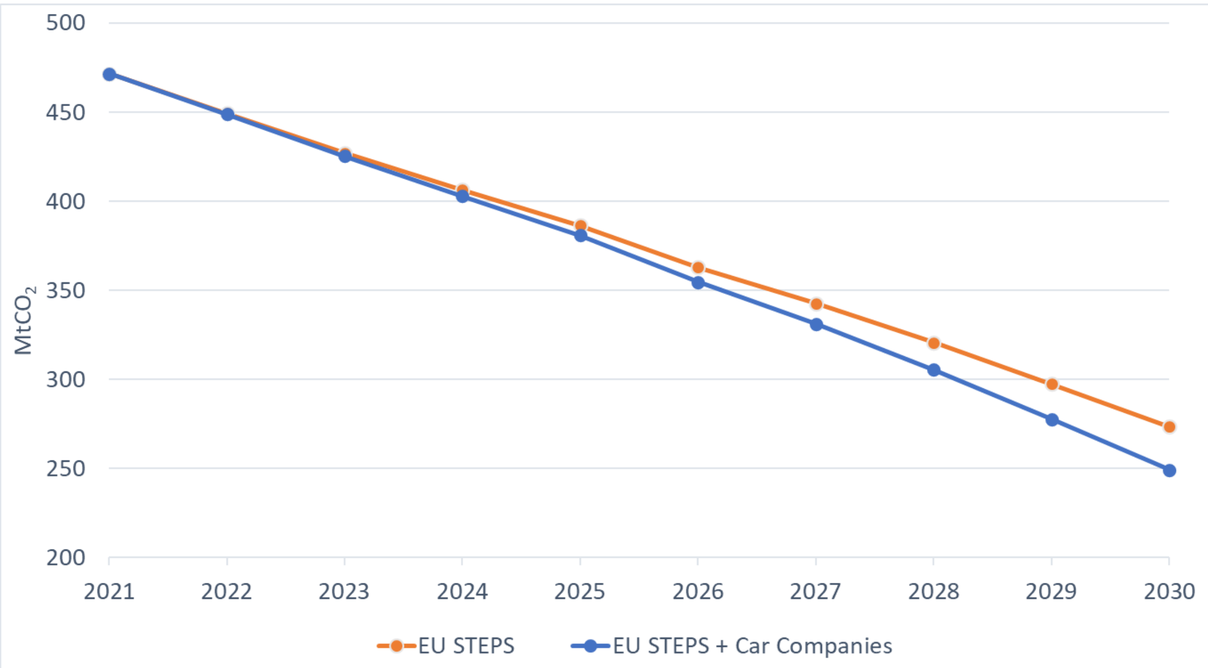
Table 13. Calculated emissions for top five car markets in model scenarios 1 & 2. Emission values are rounded.

Region	**Scenario**	**Emissions 2021-2030 ($MtCO_2$)**	**Reduction in scenario 2 ($MtCO_2$)**
EU27 + UK	1. STEPS	3,737	
	2. STEPS + car companies	3,647	-90
USA	1. STEPS	7,663	
	2. STEPS + car companies	7,586	-77
China	1. STEPS	7,160	
	2. STEPS + car companies	7,096	-64
Japan	1. STEPS	504	
	2. STEPS + car companies	502	-3
India	1. STEPS	659	
	2. STEPS + car companies	659	-1

European Union + the United Kingdom

This region had a high EV share of 77% in the second scenario, resulting from ambitious company EV targets including four car companies who already pledged to reach 100% EVs in 2030. Under the second scenario the EU27+UK would be the only leading market achieving the required share of 75% EVs by 2030 to keep a zero-carbon road transportation sector in sight (UNFCCC, 2021). The European EV development further resulted in the highest GHG emission reduction of the five included regions. Total GHG emissions between 2021 and 2030 were significantly lower for this region than the American market although we projected this region to sell 2.5 million more cars than the US in 2030.

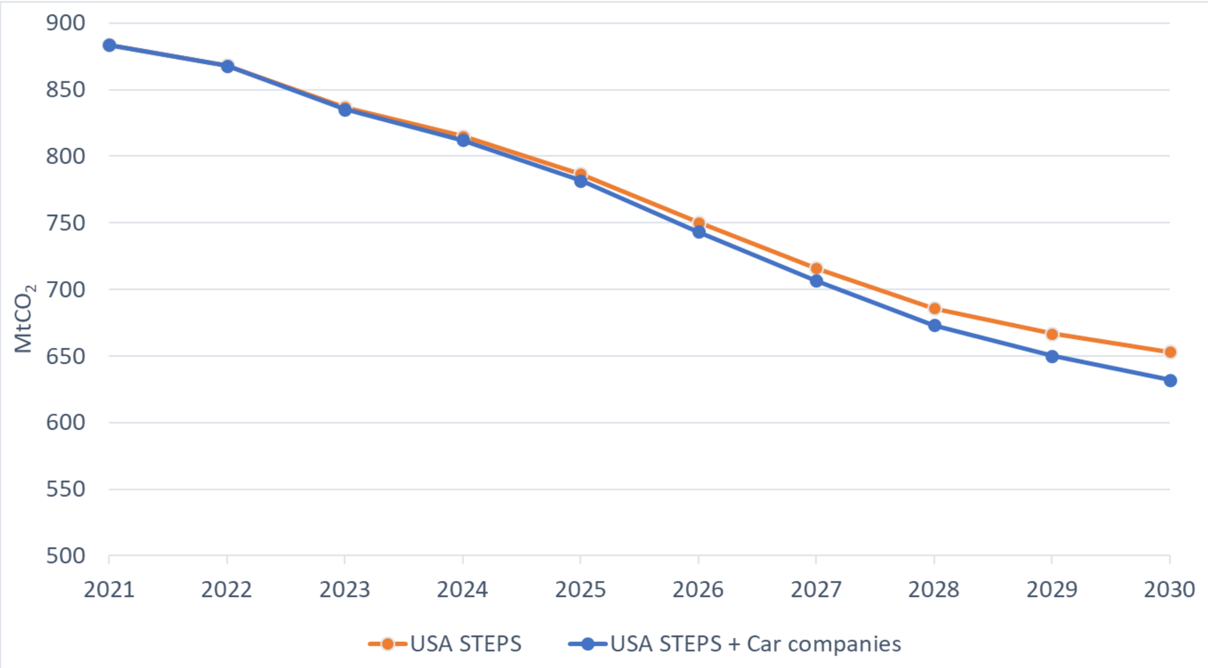
Figure 8. GHG emissions for the EU27 + UK between 2021 and 2030.



United States

We projected the highest amount of GHG emissions for the United States. This is partly explained by the US model covering a selection of more emission-intensive light-duty vehicles next to passenger vehicles. Nonetheless, even in the more ambitious scenario, the US only reached 5 million EV sales in 2030 which heavily contrasts to the projected EV uptake of the other top two markets who will both exceed 10 million EV sales. Although total emission levels were high compared to other regions, the US reached the second-largest emission reduction of 77 $MtCO_2$ between the two modelled scenarios.

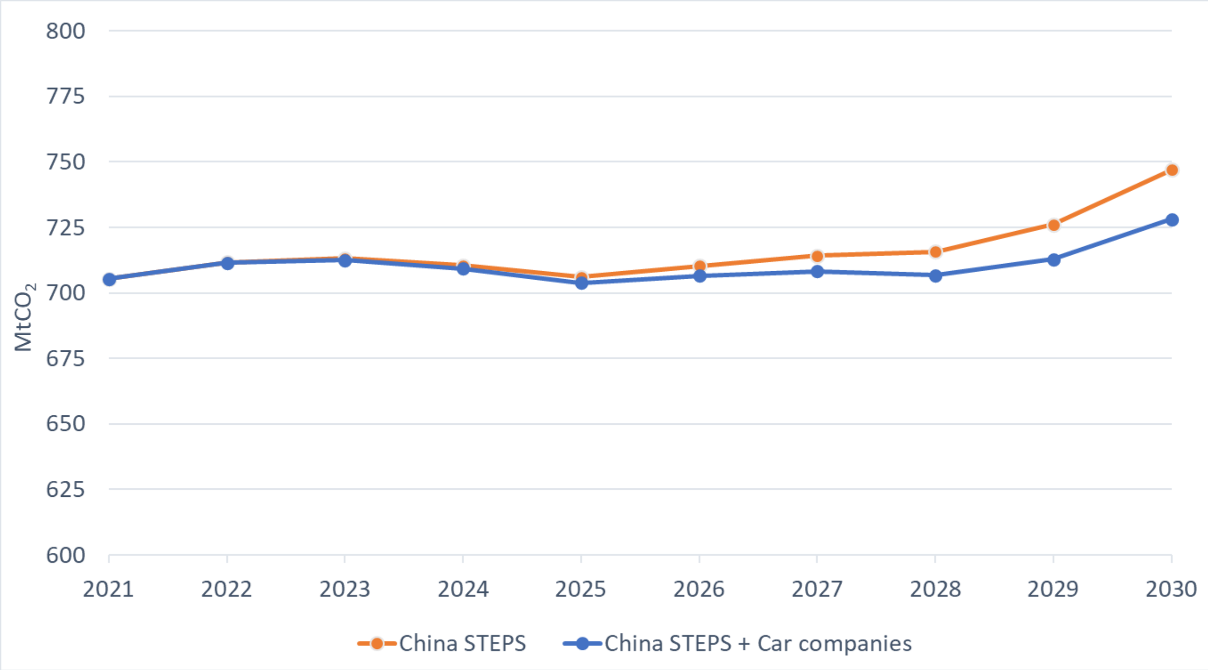
Figure 9. GHG emissions for the United States between 2021 and 2030.



China

A unique feature of the Chinese car market analysis was the rise of GHG emissions between 2021 in 2030. In the final year of the model the annual emissions of both scenarios were higher than the base year emissions of 705 Mt in 2021. In comparison, for the other four regions in this study GHG emissions steadily decreased from 2021 levels even when the possible reduction between national scenarios was minimal. One possible explanation for this finding is the high level of total person-km projected for China. Unlike other leading markets, China's projected person-km will continue to rise linearly. Therefore, we argue that the projected levels of person-km may counter part of the emission reductions caused by an increased EV uptake. Furthermore, the car companies included in this study covered only half of Chinese car sales, leaving room for additional EV development from promising Chinese EV companies beyond BYD. China will without question be the largest global EV market, so any EV target for this country can already set an example for all market that hope to follow.

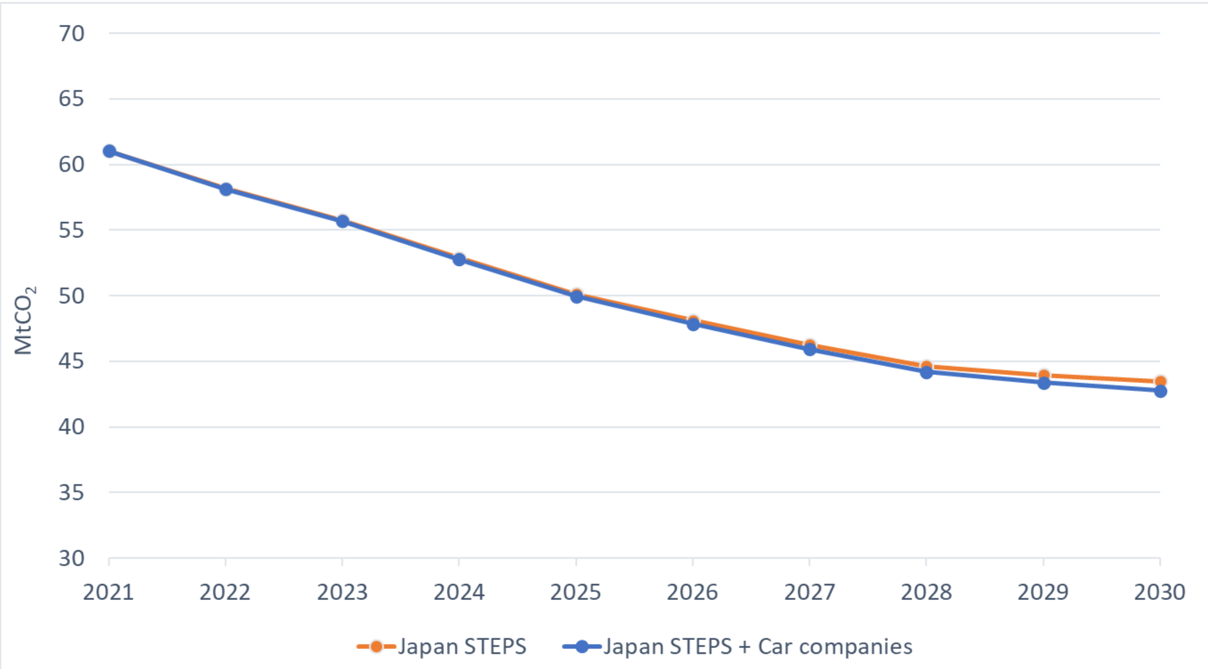
Figure 10. GHG emissions for China between 2021 and 2030.



Japan

In the scenarios for Japan, we found a small emission reduction value of 3 $MtCO_2$ after the integration of car company EV targets. On the one hand, Japan's car market was not projected to grow any further, leading to the lowest amount of GHG emission across the included regions. On the other hand, the effects of EV development as standalone reduction target were low in this particular analysis. On the other hand, the country's stance on full hybrids still leaves for additional emission reductions from BEVs and PHEVs alike.

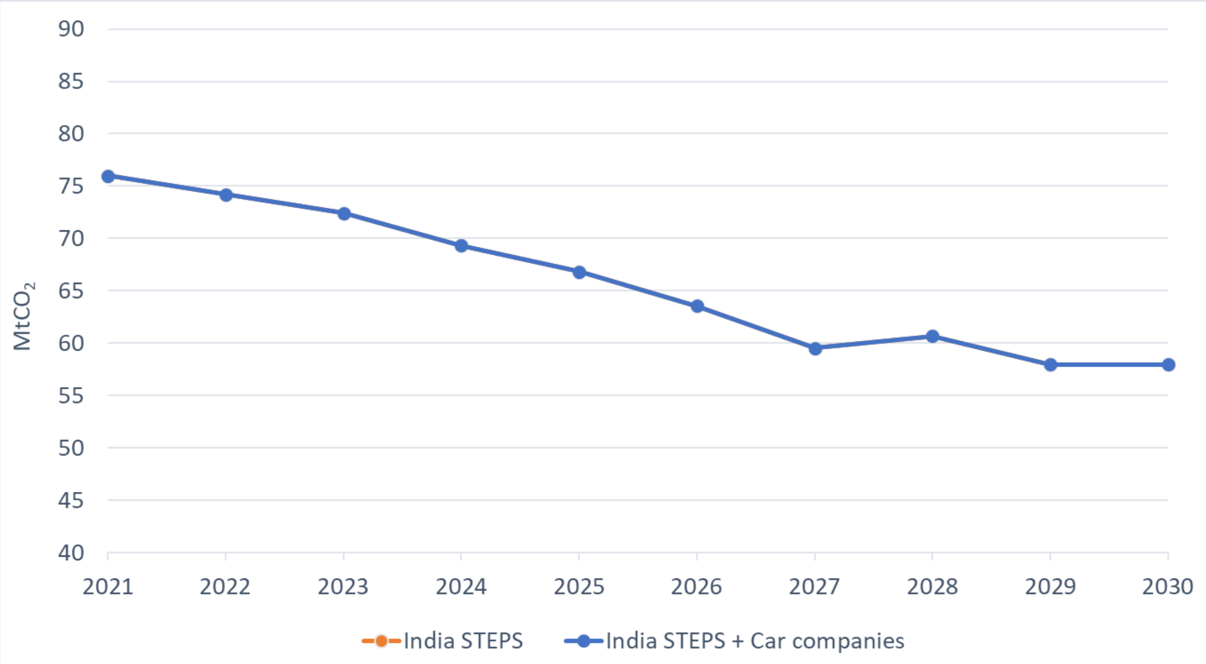
Figure 11. GHG emissions for Japan between 2021 and 2030.



India

Finally, India had the lowest downstream emission reduction potential. Although GHG emissions in the second scenario were lower than the STEPS benchmark, this difference was 1 $MtCO_2$ for the modelled period. On a more positive note, Indian's relative growth rate of projected EV shares was the highest of all regions. However, the results show that additional reduction measures beyond higher EV shares are needed to achieve higher emission reduction. In addition, the individual analysis for India included a high level of uncertainty for the next decade due to the lack of specific car company targets and any fuel performance standards after 2022. The model included more assumptions on average 2030 values compared to regions that had formulated specific targets. In conclusion, India must increase its current EV development policies if the country wishes to achieve the latest ambition of 30% EV sales in 2030.

Figure 12. GHG emissions for India between 2021 and 2030.



5. Discussion

In this section we discuss possible contributions of our findings to earlier studies. The target landscape and emission coverage results were compared with similar results based on the extensive SBTi target database. Furthermore, we compare findings from the downstream part of the research with the previous EV analysis included in the Global Aggregation Report of 2021 published by NewClimate Institute. More specifically, we discuss the effect of new EV targets in the period between February 2021 and June 2022 which indicate the cut-off dates of both analyses. Additionally, we compared GHG emission reductions from the model calculation in the three regions that were assessed before. In the section on research limitations we discuss data availability and the assumption set used for the model calculation in more detail. The chapter ends with recommendations for car companies and policy makers.

5.1. Contribution to existing literature

The results on upstream and downstream coverage from ten specific car companies in this report can be compared to similar results for the transportation sector. Upstream and downstream scope 3 emission coverage of companies in the transportation sector have recently been explored in one scheduled NewClimate Institute publication. This particular analysis was carried out as part of a steel sector deep-dive draft report that is set for publication in 2022 and compared emission reduction across steel end-use categories (de Villafranca et al., 2022). The report assessed upstream and downstream coverage of targets for all vehicles (including ships, trucks or aviation) and the subsector automobiles and components. We contributed to these results by adding another subsector for car companies by excluding parts and components companies from the automobiles and components category. The SBTi database was used to analyse scope 3 coverage of various end-use steel categories, of which we focus on transportation in this comparison (SBTi, 2022). This included the seven car companies included in the current analysis who had set science-based reduction targets.

In the SBTi database, 97 companies in the transport sector announced emission reduction targets, 61 of which included mentions of scope 3 (70%). In comparison, this percentage was 62% in this analysis. De Villafranca et al. assessed the total upstream and downstream coverage of these scope 3 targets similar to the results in section 4.2. The full table with the upstream and downstream division of scope 3 targets from both analyses can be seen below. As the 'vehicles' category included other modes of transport, results were also presented for (1) the subsector 'automobiles and components' (34 companies in total) and (2) for the companies that were major car companies instead of automobile component manufacturers (10 companies).

Table 14. Upstream and downstream target coverage between the full vehicle sector, its car-based subsector automobiles and components, and the ten included car companies in these two categories found in similar analysis (adapted from results from de Villafranca et al. (2022) and SBTi (2022)).

	N=61	N=34	N=10
Category	**Vehicles (incl. ships, trucks etc.)**	**Automobiles & components**	**Car companies only**
Upstream only	5%	6%	10%
Downstream only	20%	32%	90%
Upstream + downstream	2%	3%	0%
Uncertain	51%	44%	10%
Measure and reduce	23%	15%	0%
Total upstream	7%	9%	10%
Total downstream	21%	35%	90%

The total upstream coverage of scope 3 targets slightly grew from 7% for all vehicles to 9% in the passenger car subsector automobiles and components. However, downstream targets still dominated the targets in this subsector. For a fair comparison with the current analysis we must compare results for car companies only by excluding automobile component manufacturers from this subsector. These results are presented in table 15. The NewClimate Institute analysis found a low share of upstream scope 3 emissions covered by reduction targets, covering 5-10% of car company targets in the three sectors included in table 14. These values were similar to the results in section 4.1 of this research, which included even lower upstream coverages of below 5%. It must be noted that the number of targets and the selection of included car companies was not equal across the two columns in table 15 below. Furthermore, de Villafranca et al. also included a separate target category for measure and reduce and found more companies that did not specify upstream or downstream efforts (i.e. the category 'uncertain'). This further explained differences between the two analyses. Nevertheless, both results show that downstream-specific targets are consistently the largest category. Similar to the landscape analysis results, the SBTi database also included only one of ten car companies that had announced an upstream scope 3 target.

Table 15. Comparison between scope 3 targets from car companies between results from de Villafranca et al. (2022) and the current study. The presented results include specific scope 3 targets for car companies only. Targets were retrieved from ten car companies, with seven of them covered in both studies.

	de Villafranca et al. (2022)	**Current study**
Upstream only	10%	3%
Downstream only	90%	86%
Upstream + downstream	0%	8%
Uncertain	0%	3%
Upstream total	10%	11%
Downstream total	90%	95%

For a second comparison, collected EV targets were compared with results from the Global Aggregation Report 2021 that have been summarized in table 16 (NewClimate Institute et al., 2021).

*Table 16: EV targets resulting from NewClimate Institute et al (2021) in February of 2021. Targets with * were calculated based on absolute EV sales targets and future sales projections.*

Car company	**EV share target**	**Target year**
Toyota	14%*	2030
Volkswagen	22.5% 40%	2025 2030
General Motors	70% 100%	2030 2035
Stellantis *FCA* *Peugeot (part of PSA)*	 No target 50%	 - 2025
Hyundai-Kia	*Not analysed*	*Not analysed*
Honda	66.6%	2030
Ford	No target	-
Nissan	18%*	2022
Renault	50%	2025
Mercedes-Benz	25% 50%	2025 2030

The values in table 16 were used as a starting point of the EV analysis in this report, but the majority of targets have since been replaced by more ambitious targets (see annex III). Most importantly, these results showed how Nissan, Ford, Renault and Stellantis did not have any target for 2030 until February 2021, but have added them in the meantime. Only Honda and General Motors did not present updates for target year 2030. Honda's previous targets included HEVs in the EV share and although General Motors still targets 100% sales in 2035, the current plans align with roughly 50% instead of the targeted 70%. Most intermediate targets for 2025 have also increased except for Volkswagen's target. In contrast, this company slightly reduced the targeted EV share to 20% instead of the 22.5% found earlier. This suggests that the current EV development of car companies might not always be aligned with their announced long-term EV ambitions and companies may also lower previously announced targets instead of improving them. This is an important consideration for future car company assessments and comparing them with earlier editions.

In addition to company targets, we can compare national EV policies and fuel targets that were included in the previous analysis for the EU27 + UK, the United States and China. The national targets from these three regions that were retrieved from NewClimate Institute et al. are presented in table 17 below. While the current state of EV targets significantly changed for car companies, the updated collection of national targets has so far mostly been limited to announced policies rather than official targets.

Table 17. National EV and fuel efficiency targets for EU27+UK, US and China (NewClimate Institute et al., 2021).

	EU-27+UK	US	China
Fuel efficiency standard new vehicles	(implemented) 95 gCO_2/km by 2020 80.8 gCO_2/km by 2020 59.4 gCO_2/km by 2020	(implemented) 5.82 l/100km by 2026 (projection) 44.5 mpg by 2030	(implemented) 5.0 l/100km by 2020 (planned/announcement) 4.0 l/100km by 2025 3.2 l/100km by 2030
EV targets new vehicles	(implemented) 15% by 2025 30% by 2030	(national study) 5% by 2030	(implemented) 20% (new energy vehicles: NEVs) by 2020 (announcement) 25% (NEVs) by 2025 50-60% by 2030

First of all, the EU's and China's fuel performance targets did not change in the additional research period between February 2021 and June 2022. As a result, our GHG emission model replicated the fuel efficiency standards that were implemented for these two regions. The only major update is the change in China's announcement for 2025 which seems to have become an official target. In contrast, the US has improved their fuel performance standards until target year 2026. The latest standards equate to an average fuel efficiency of 4.8L/100km (or 49 mpg) in 2026 which is a significant improvement compared to the previous value of 5.82 L/100 km in table 17 (Collie, 2022). Final US values were published in December 2021, making the US the only of these three regions that has updated fuel economy standards after the NewClimate Institute publication.

For national EV targets, we noticed the same pattern for these three regions. For instance, the EU's EV targets for 2025 and 2030 remain active. China has now presented an official target of 20% EVs in 2025 which has been lowered from the earlier announcement of 25% included in table 17. Similarly, China's latest ambition of 40% NEVs in 2030 is still lower than the projected EV share of 50-60% included in table 17. For EV targets the United States again provided the largest improvement by formulating the first federal EV ambition of 50%. This ambition would result in a significant increase of the estimated 5% in the previous research, although it is not yet translated into an official policy.

Additionally, we compare emission model results between the two analyses. Similar to the current study, NewClimate Institute et al. modelled the additional EV increase from car companies compared to national stated policies. This resulted in total GHG reduction estimates between 2021 and 2030 of 113 $MtCO_2$ for the EU27+UK, 108 $MtCO_2$ for the US and 22 $MtCO_2$ for China in the scenario where company targets were added to the national policies. When we compare the model results of the current study which were retrieved based on a similar methodology, we found lower emission reductions for the European and American markets but significantly higher reductions for China.

5.2. Research limitations

Research limitations were mostly caused by the limited data availability throughout the research process. This occurred mostly during the upstream analysis on steel which required a change in methods for this section. In fact, overall steel mentions were so low that additional information on supplier requirements and lightweighting literature estimates were later added to the upstream section. As a result, we were not able to fully assess upstream reduction potentials in a quantitative way similar to the downstream sections of the paper. For the creation of the GHG reduction model, we were limited to simplified assumptions in situations were data was insufficient. A notable example was the lower level of detailed data provided in STEPS projections for Japan and the specific EU27+UK region.

A second research limitation was caused by the differences across data sources. We included multiple sources for the target collection, consisting of annual sources (i.e. CDP and sustainability reports) and continuous target updates provided in news releases. For example, we found instances of a specific target that changed its targeted EV share between two different sources. Furthermore, CDP responses sporadically included company targets with expired target years or targets in the wrong category. Another example was the remarkable difference between General Motors' scope 3 emissions presented in the latest sustainability report and the value in the additional data centre which was 37 Mt. As such, it was not always possible to analyse with certainty to what extent earlier targets had been updated or replaced and which targets could be defined as new. To ensure optimal inclusion of targets we also treated intermediate or updated versions of targets derived from other larger targets as completely new. This also explained the relatively high number of targets retrieved from only ten car companies.

The main implication of national targets was the current state of these targets according to IEA's definitions (i.e. official target vs ambition). This difference between official targets and unofficial ambitions was crucial, as many ambitions would significantly increase national EV uptakes when fully achieved. For example, India and the United States did not present official EV targets, but recently announced the first EV ambitions that can bridge their current EV gap with China and the European Union. Because various EV ambitions were not yet official, we made the choice of using STEPS values, which reflected official EV targets on national level. With this choice we accounted for the fact that not all of the recently announced ambitions would be fully integrated in reality. Alternatively, a similar analysis which is based on the announced policies scenario (APS) as reference scenario might compare EV ambitions to a more ambitious benchmark. Considering the rapidly changing and developing landscape of EV targets that we observed in 2022 specifically, comparing company targets with these APS values might become a useful method to assess EV target development in the next years if global EV ambitions continue to develop at this rate.

Finally, we touch upon additional factors that may affect the future of the car manufacturing sector but could not be specifically included in this analysis, of which financial considerations were the most important. In the upstream results we observed that steel and battery strategies were often presented in monetary values instead of reduction from an emission perspective. Moreover, studies on ownership costs were the second most common topic directly after studies on GHG emissions in the lightweighting literature review by Luk et al. (2017). Especially in this industry where many processes are designed with optimal cost-optimal efficiency, sudden changes in raw material costs may challenge the practical implementation of lightweighting measures or battery production facilities. The start of the Russia-Ukraine conflict in February 2022 provided a recent example of increased raw material costs taking place during the research period. This conflict affected the European car market sales and increased global prices of crucial car manufacturing minerals such as nickel and iron (Ferris, 2021). The research objective did not aim to include cost considerations, but car companies and countries may naturally lower their EV ambitions when the economic feasibility of these measures is at risk. Furthermore, we did not correct for any behavioural changes that are needed to reach road transport decarbonization. For instance, in their pathway towards a zero carbon road transportation sector the UNFCCC (2021) estimates that 15% of the required emission reductions can be achieved through changes of behaviour in this sector. Ride-sharing and car-sharing in particular can add further significant emission reductions on top of reduction measures included in this paper such as increased recycling strategies and lightweighting (IRP, 2020). Large-scale behavioural changes can thus further improve the effect of existing emission reduction measures towards the car sector's decarbonization in the long term.

5.3. Recommendations

Following the lack of upstream targets and the limited coverage of steel in particular, we mainly recommend stronger policies to include upstream scope 3 emissions in car manufacturing. Supply chain auditing and supplier requirements might indirectly cover part of these emissions, but more direct reduction targets for upstream supply chains are needed. Additionally, we recommend better coverage of steel in company sustainability reporting because the coverage of this material is low compared to other materials. For batteries, we recommend car companies to develop their strategies as quickly as company EV targets have recently developed so that they achieve the increased battery capacity that is needed for the targeted levels of EV implementation. Furthermore, contributing to upstream scope 3 research with more quantitative data would be a crucial step towards a better estimation of upstream reduction potentials. Likewise, increased upstream emission coverage from NSAs can facilitate the ongoing research efforts to map the geographical location of scope 3 emissions across the global car manufacturing supply chains, which was not possible based on current company data in this study.

Another recommendation for car companies is to increase overall transparency of scope 3 emission reporting in public sustainability reports to ensure more accurate quantifications of reduction potentials from announced corporate targets. This includes reporting of supply chain, raw material or GHG emission data as well as presenting reduction targets and innovation strategies on steel and EV battery developments. Companies increasingly included scope 3 emissions in sustainability reports, but there are individual differences between the level of data disclosure. Overall transparency would increase if all car companies reported scope 3 data similar to their CDP questionnaire responses in which they all included complete emission inventories. In addition, CDP data is not public, leaving sustainability reports as a company's main document to present climate ambitions to the general public, scholars and policy makers alike.

For national policy makers we recommend increased ambition levels of national EV policies following the rapid development of car company EV targets in the included research period. In their announced targets car companies have shown willingness to rapidly adjust their EV production and sales in the coming decade and continue the rise of EV implementation. National policies are recommended to follow this example given by the car companies and, in turn, provide an additional incentive for the companies to increase EV sales in key car markets.

6. Conclusion

In this study we attempted to assess the current state of scope 3 emission coverage in the car manufacturing sector. The research objective included an estimation of the upstream and downstream GHG reduction potentials from car company targets in comparison to national policies. We conclude that the scope 3 targets of ten global car companies are dominated by downstream-based activities. Despite causing 15% of a car's GHG emissions, upstream supply chains were only directly mentioned in one of 79 collected company targets. The exclusion of this category resulted in reduction targets covering an estimated 80-90% of total emissions in the car supply chain. Therefore, the emission reduction potentials from current targets systematically exclude a part of potential emissions that can only be mitigated with more specific upstream-based measures.

Estimating upstream scope 3 GHG reduction potentials is additionally challenging because overall mentions of quantitative steel and EV battery strategies were low in company sustainability reporting. Possible reduction measures like vehicle lightweighting or high-strength steel provided in literature were increasingly mentioned, but did not provide many quantitative emission reduction potentials. Companies included more short-term battery developments, but reduction estimations also remain limited as most plans are currently in early stages of development. Therefore, we were not able to present a quantitative upstream reduction potential based on car company reduction targets and sustainability reporting. Better synergies between literature estimates and announced company strategies must clarify the reduction potentials of batteries and most notably steel. Unique technologies, critical material reduction and increased EV production capacity have already been established by some car companies and can potentially be expanded further in the long-term. We argue that the coming years will become crucial for possible large-scale EV uptake and any further quantitative upstream potential estimations, as more announced strategies will have reached full operational status.

In contrast to the upstream analysis, downstream scope 3 reduction targets and particularly electric mobility are continuously improving. EV targets from car companies have skyrocketed in 2021 and 2022, resulting in the average level of targeted EV sales exceeding the existing EV targets on national level under IEA STEPS. Although national targets also include increased EV sales and revised fuel performance standards, company EV targets are clearly developing faster and include higher EV shares as well. We made an effort to quantify this difference by modelling EV reduction potentials from EV targets in the top five car markets. In this model total GHG emissions were lower for all five regions in the second scenario when average EV shares from corporate targets were added to the emission levels from national policies alone. In summary, we found minimal emission reductions of 1 and 3 Mt of CO_2 for India and Japan, respectively. Reduction potentials for China and the US were estimated at 64 and 77 $MtCO_2$, with the EU27+UK accounting for the largest potential reduction of 90 $MtCO_2$ of in 2030.

In conclusion, this study showed both the lack of upstream and the increase of downstream scope 3 emission strategies from car companies. We recommend future policies that stimulate a similar development of upstream strategies like steel to tackle the limited emission reduction potentials that we identified in company reporting. In addition, we encourage national downstream policies to follow the companies' example of rapidly growing EV targets in major car markets. Finally, we argue that the car companies' rise of announced battery technologies and ambitious EV sales target until 2030 highlighted 2022 as a crucial moment for policy makers to act if the car's sector emissions are to significantly reduce at the end of this decade.

References

Abe, M. (2013). *Expansion of global value chains in Asian developing countries: automotive case study in the Mekong subregion*. United Nations ESCAP. https://repository.unescap.org/handle/20.500.12870/393

Andonova, L. B., Hale, T. N., & Roger, C. B. (2017). National Policy and Transnational Governance of Climate Change: Substitutes or Complements? *International Studies Quarterly*, *61*(2), 253–268. https://doi.org/10.1093/isq/sqx014

Arshi, P., & Sinistore, J. (2022, March 4). *Similarities, Differences and Synergies of Life Cycle Assessment and Greenhouse Gas Inventory Methods*. https://www.wsp.com/en-us/insights/2022-life-cycle-assessment-and-greenhouse-gas-inventory

Bieker, G. (2021). *A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars*. https://www.alectra.com/sites/default/files/assets/pdf/Global_LCA_passenger_cars-07_2021.pdf

Bushi, L. (2014). *Comparative LCA Study of EDAG Silverado Body Lightweighting Magna Ultralight Door Project View project Magna Ultralight Door Project View project*. https://www.researchgate.net/publication/329151102

Bushi, L., Skszek, T., & Reaburn, T. (2018). Magna's New Ultralight Door - A Comparative LCA Study of the Lightweight Design as per ISO 14040/44 LCA Standards and CSA Group LCA Guidance Document for Auto Parts. *SAE Technical Papers*, *2018-April*. https://doi.org/10.4271/2018-01-0661

CDP. (2020). *CDP Climate Change 2020 Reporting Guidance*. CDP Worldwide. Available at https://guidance.cdp.net/en/guidance?cid=13&ctype=theme&idtype=ThemeID&incchild=1&microsite=0&otype=Guidance&tags=TAG-13069%2CTAG-605%2CTAG-600

CDP. (2021). *CDP Climate Change 2021 Reporting Guidance*. CDP Worldwide. Available at https://guidance.cdp.net/en/guidance?cid=18&ctype=theme&idtype=ThemeID&incchild=1&microsite=0&otype=Guidance&page=1&tags=TAG-646%2CTAG-605%2CTAG-599

Climate Action Tracker. (2017). *Manufacturing a low-carbon society: how can we reduce emissions from cement and steel?* https://climateactiontracker.org/documents/60/CAT_2017-10-18_DecarbIndustry_CATAnalysis.pdf

Collie, S. (2022, April 4). *USA commits to stricter fuel economy standards*. CarExpert. https://www.carexpert.com.au/car-news/usa-commits-to-stricter-fuel-economy-standards

de Villafranca, M. J., Smit, S., Nilsson, A., Beuerle, J., & Kuramochi, T. (2022). *Global steel: climate commitments and quantifying their mitigation potential*. NewClimate Institute [Draft report]

Deetman, S. P. (2021). *Stock-driven scenarios on global material demand: the story of a lifetime*. https://hdl.handle.net/1887/3245696

Environmental Protection Agency. (2016, March). *Life-Cycle GHG Accounting Versus GHG Emission Inventories*. U.S. EPA. https://www.epa.gov/sites/default/files/2016-03/documents/life-cycle-ghg-accounting-versus-ghg-emission-inventories10-28-10.pdf

Environmental Protection Agency. (2021). *Revised 2023 and Later Model Year Light-Duty Vehicle Greenhouse Gas Emissions Standards*. EPA. Washington, DC, USA. https://www.govinfo.gov/content/pkg/FR-2021-12-30/pdf/2021-27854.pdf

European Commission, Directorate-General for Climate Action, Hill, N., Amaral, S., Morgan-Price, S., Nokes, T., Bates, J., Helms, H., Fehrenbach, H., Biemann, K., Abdalla, N., Jöhrens, J., Cotton, E., German, L., Harris, A., Haye, S., Sim, C., Bauen, A., & Ziem-Milojevic, S. (2020). *Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA: final report*. Publications Office. https://doi.org/doi/10.2834/91418

EV Database. (2022). *Energy consumption of full electric vehicles*. Retrieved April 16, 2022, from https://ev-database.org/cheatsheet/energy-consumption-electric-car

FCA. (2021). *2020 Sustainability Report*. Fiat Chrysler Automobiles. https://www.stellantis.com/content/dam/stellantis-corporate/sustainability/csr-disclosure/fca/fca_2020_sustainability_report.pdf

Ferris, R. (2021, April 16). *How Russia's war is cutting global auto production*. CNBC. https://www.cnbc.com/2022/04/16/how-russias-war-is-cutting-global-auto-production.html

Ford. (2021). *Integrated Sustainability and Financial Report 2021*. Ford Motor Company. https://media.ford.com/content/dam/fordmedia/North%20America/US/2021/03/31/Ford-Integrated-Report-2021.pdf

Ford. (2022). *Integrated Sustainability and Financial Report 2022*. Ford Motor Company. https://corporate.ford.com/content/dam/corporate/us/en-us/documents/reports/integrated-sustainability-and-financial-report-2022.pdf

General Motors. (2021). *2020 Sustainability Report*. https://www.gmsustainability.com/_pdf/resources-and-downloads/GM_2020_SR.pdf

General Motors. (2022). *2021 Sustainability Report*. https://www.gmsustainability.com/_pdf/resources-and-downloads/GM_2021_SR.pdf

Greene, S. E. (2017). What are we missing? Scope 3 greenhouse gas emissions accounting in the metals and minerals industry. *Matériaux & Techniques*, *105*(5–6), 503. https://doi.org/10.1051/mattech/2018014

Greenhouse Gas Protocol. (2004). *Greenhouse gas protocol - A corporate accounting and reporting standard*. Revised Edition. World Resources Institute and World Business Council for Sustainable Development

Greenhouse Gas Protocol. (2011). *Corporate value chain (scope 3) accounting and reporting standard*. World Resources Institute and World Business Council for Sustainable Development

Günther, H.-O., Kannegiesser, M., & Autenrieb, N. (2015). The role of electric vehicles for supply chain sustainability in the automotive industry. *Journal of Cleaner Production*, *90*, 220–233. https://doi.org/10.1016/j.jclepro.2014.11.058

Hale, T. N., Chan, S., Hsu, A., Clapper, A., Elliott, C., Faria, P., Kuramochi, T., McDaniel, S., Morgado, M., Roelfsema, M., Santaella, M., Singh, N., Tout, I., Weber, C., Weinfurter, A., & Widerberg, O. (2021). Sub- and non-state climate action: a framework to assess progress, implementation and impact. *Climate Policy*, *21*(3), 406–420. https://doi.org/10.1080/14693062.2020.1828796

Hertwich, E. G., & Wood, R. (2018). The growing importance of scope 3 greenhouse gas emissions from industry. *Environmental Research Letters*, *13*(10), 104013. https://doi.org/10.1088/1748-9326/aae19a

Honda. (2022). *Honda Sustainability Report 2021*. https://global.honda/content/dam/site/global/about/cq_img/sustainability/report/pdf/2021/Honda-SR-2021-en-all.pdf

Hsu, A., Höhne, N., Kuramochi, T., Roelfsema, M., Weinfurter, A., Xie, Y., Lütkehermöller, K., Chan, S., Corfee-Morlot, J., Drost, P., Faria, P., Gardiner, A., Gordon, D. J., Hale, T., Hultman, N. E., Moorhead, J., Reuvers, S., Setzer, J., Singh, N., … Widerberg, O. (2019). A research roadmap for quantifying non-state and subnational climate mitigation action. *Nature Climate Change*, *9*(1), 11–17. https://doi.org/10.1038/s41558-018-0338-z

Hyundai. (2021). *2021 Sustainability Report*. Hyundai Motor Company. https://www.hyundai.com/content/hyundai/ww/data/csr/data/0000000049/attach/english/hmc-2021-sustainability-report-en-v6.pdf

Institutional Investors Group on Climate Change, & 2° Investing Initiative. (2020). *Changing gear - Alignment of major auto manufacturers with the goals of the Paris Agreement*. https://www.iigcc.org/download/changing-gear-alignment-of-major-auto-manufactuerers-with-goals-of-the-paris-agreement/?wpdmdl=3457&refresh=61bb3cd40c9191639660756

International Council on Clean Transportation. (2020, May). *Data for ICCT global fuel efficiency comparison charts [Data set]*. Retrieved April 14, 2022, from https://theicct.org/pv-fuel-economy/

International Council on Clean Transportation. (2021). *Global passenger car market share of countries planning to phase out new sales of internal combustion engine vehicles*. https://theicct.org/sites/default/files/publications/pvs-global-phase-out-FS-oct21.pdf

International Energy Agency. (2020). *Iron and Steel Technology Roadmap*. IEA, Paris. https://www.iea.org/reports/iron-and-steel-technology-roadmap

International Energy Agency. (2021a). *Global EV Outlook 2021*. IEA, Paris. https://www.iea.org/reports/global-ev-outlook-2021

International Energy Agency. (2021b). *World Energy Outlook 2021*. IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2021

International Energy Agency. (2022a). *Global Energy and Climate Model*. IEA, Paris. https://www.iea.org/reports/global-energy-and-climate-model, License: CC BY 4.0

International Energy Agency. (2022b). *Global EV Data Explorer*. IEA, Paris. Retrieved May 20, 2022, from https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

International Energy Agency. (2022c). *Global EV Outlook 2022*. IEA, Paris. https://www.iea.org/reports/global-ev-outlook-2022

International Energy Agency. (2022d). *Global EV Policy Explorer*. IEA, Paris. Retrieved April 4, 2022, from https://www.iea.org/data-and-statistics/data-tools/global-ev-policy-explorer

International Resource Panel. (2020). *Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future*. Hertwich, E., Lifset, R., Pauliuk, S., Heeren, N. A report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya. https://doi.org/10.5281/zenodo.3542680

Kaplinsky, R., & Morris, M. (2001). *A Handbook for Value Chain Research*. *113*.

Kawajiri, K., Kobayashi, M., & Sakamoto, K. (2020). Lightweight materials equal lightweight greenhouse gas emissions?: A historical analysis of greenhouse gases of vehicle material substitution. *Journal of Cleaner Production*, *253*, 119805. https://doi.org/10.1016/J.JCLEPRO.2019.119805

Kawamoto, R., Mochizuki, H., Moriguchi, Y., Nakano, T., Motohashi, M., Sakai, Y., & Inaba, A. (2019). Estimation of CO2 Emissions of Internal Combustion Engine Vehicle and Battery Electric Vehicle Using LCA. *Sustainability*, *11*(9), 2690. https://doi.org/10.3390/su11092690

Kelly, J., & Dai, Q. (2021). Life-cycle analysis of vehicle lightweighting: a review. *Electric, Hybrid, and Fuel Cell Vehicles*, 91–104.

Khan, N. (2022, May 27). *ETAuto Forecast 2022: Is India's 5 million PV sales dream dashed forever?* ETAuto. https://auto.economictimes.indiatimes.com/news/passenger-vehicle/etauto-forecast-2022-is-indias-5-million-pv-sales-dream-dashed-forever/91830114?redirect=1

Kia. (2021). *Kia Sustainability Magazine 2021*. Kia Motors. https://worldwide.kia.com/int/company/sustainability/sustainability-report

Kim, H. C., & Wallington, T. J. (2016). Life Cycle Assessment of Vehicle Lightweighting: A Physics-Based Model To Estimate Use-Phase Fuel Consumption of Electrified Vehicles. *Environmental Science & Technology*, *50*(20), 11226–11233. https://doi.org/10.1021/acs.est.6b02059

Knobloch, F., Hanssen, S. v., Lam, A., Pollitt, H., Salas, P., Chewpreecha, U., Huijbregts, M. A. J., & Mercure, J.-F. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time. *Nature Sustainability*, *3*(6), 437–447. https://doi.org/10.1038/s41893-020-0488-7

Kong, A., Zheng, M., Zhang, X., Choi, E., Cobbing, M., Kim, J., & Read, D. (2021). *Auto Environmental Guide - A comparative analysis of global automakers' decarbonisation: recent action and future plans*. Greenpeace East Asia (GPEA). https://www.greenpeace.org/static/planet4-eastasia-stateless/2021/11/47de8bb4-gpea_auto_environmental_guide_2021.pdf

Kuramochi, T., Roelfsema, M., Hsu, A., Lui, S., Weinfurter, A., Chan, S., Hale, T., Clapper, A., Chang, A., & Höhne, N. (2020). Beyond national climate action: the impact of region, city, and business commitments on global greenhouse gas emissions. *Climate Policy*, *20*(3), 275–291. https://doi.org/10.1080/14693062.2020.1740150

Lui, S., Kuramochi, T., Smit, S., Roelfsema, M., Hsu, A., Weinfurter, A., Chan, S., Hale, T., Fekete, H., Lütkehermöller, K., Jose de Villafranca Casas, M., Nascimento, L., Sterl, S., & Höhne, N. (2021). Correcting course: the emission reduction potential of international cooperative initiatives. *Climate Policy*, *21*(2), 232–250. https://doi.org/10.1080/14693062.2020.1806021

Luk, J. M., Kim, H. C., de Kleine, R., Wallington, T. J., & MacLean, H. L. (2017). Review of the Fuel Saving, Life Cycle GHG Emission, and Ownership Cost Impacts of Lightweighting Vehicles with Different Powertrains. *Environmental Science and Technology*, *51*(15), 8215–8228. https://doi.org/10.1021/acs.est.7b00909

Märtz, A., Plötz, P., & Jochem, P. (2021). Global perspective on CO2 emissions of electric vehicles. *Environmental Research Letters*, *16*(5), 054043. https://doi.org/10.1088/1748-9326/abf8e1

Mercedes-Benz. (2021). *Sustainability Report 2020*. Daimler AG. https://sustainabilityreport.daimler.com/2020/servicepages/downloads/files/daimler-sr-2020.pdf

Mercedes-Benz. (2022). *Sustainability Report 2021*. Mercedes-Benz. https://group.mercedes-benz.com/documents/sustainability/other/mercedes-benz-sustainability-report-2021.pdf

Modaresi, R., Pauliuk, S., Løvik, A. N., & Müller, D. B. (2014). Global Carbon Benefits of Material Substitution in Passenger Cars until 2050 and the Impact on the Steel and Aluminum Industries. *Environmental Science & Technology*, *48*(18), 10776–10784. https://doi.org/10.1021/es502930w

NewClimate Institute, Data-Driven Envirolab, Utrecht University, German Development Insitute/Deutsches Institüt für Entwicklungpolitik (DIE), CDP, Blavatnik School of Government, & University of Oxford. (2021). *Global climate action from cities, regions and businesses*. 2021 edition. Research report prepared by the team of: Takeshi Kuramochi, Sybrig Smit, Frederic Hans, Julia Horn, Katharina Lütkehermöller, Leonardo Nascimento, Julie Emmrich, Niklas Höhne, Angel Hsu, Brendan Mapes, Xuewei Wang, Mark Roelfsema, Sander Chan, Andrew Deneault, Bianca de Souza Nagasawa, Mishel Mohan, Megan Whitney, Johannes Brehm, Jonathan Hassel, Andrew Clapper, Abhishek Hiremath, Thomas Hale.

Nissan. (2021). *Sustainability Report 2021*. Nissan Motor Corporation. https://www.nissan-global.com/EN/DOCUMENT/PDF/SR/2021/SR21_E_All.pdf

Plötz, P., Link, S., Ringelschwendner, H., Keller, M., Moll, C., Bieker, G., Dornoff, J., & Mock, P. (2022). *Real-world usage of plug-in hybrid vehicles in Europe: a 2022 update on fuel consumption, electric driving and CO2 emissions*. ICCT. https://theicct.org/wp-content/uploads/2022/06/real-world-phev-use-jun22-1.pdf

PSA. (2021). *2020 Corporate Social Responsibility Report*. Groupe PSA. https://www.stellantis.com/content/dam/stellantis-corporate/sustainability/csr-disclosure/psa/groupe_psa_2020_csr_report.pdf

Qiao, Q., Zhao, F., Liu, Z., He, X., & Hao, H. (2019). Life cycle greenhouse gas emissions of Electric Vehicles in China: Combining the vehicle cycle and fuel cycle. *Energy*, *177*, 222–233. https://doi.org/10.1016/j.energy.2019.04.080

Qiao, Q., Zhao, F., Liu, Z., Jiang, S., & Hao, H. (2017). Cradle-to-gate greenhouse gas emissions of battery electric and internal combustion engine vehicles in China. *Applied Energy*, *204*, 1399–1411. https://doi.org/10.1016/j.apenergy.2017.05.041

Renault. (2021). *Climate Report April 2021*. Groupe Renault. https://www.renaultgroup.com/wp-content/uploads/2021/04/220421_climate-report-renault-group_8mb.pdf

Roelfsema, M., Harmsen, M., Olivier, J. J. G., Hof, A. F., & van Vuuren, D. P. (2018). Integrated assessment of international climate mitigation commitments outside the UNFCCC. *Global Environmental Change*, *48*, 67–75. https://doi.org/10.1016/j.gloenvcha.2017.11.001

Science Based Target Initiative. (2021). *SBTi Progress Report 2020*. https://sciencebasedtargets.org/resources/files/SBTiProgressReport2020.pdf

Science Based Target initiative. (2022). *Companies taking action [Data set]*. Science Based Targets. https://sciencebasedtargets.org/companies-taking-action

Smit, S. S. (2019). *Addressing overlaps in non-state and subnational climate action aggregation analyses*. [Master's thesis, Utrecht University]. https://dspace.library.uu.nl/bitstream/handle/1874/393829/Smit_6236308_SD_EM_MasterThesis_

Stellantis. (2022). *2021 Corporate Social Responsibility Report*. Stellantis NV. https://www.stellantis.com/content/dam/stellantis-corporate/sustainability/csr-disclosure/stellantis/2021/Stellantis_2021_CSR_Report.pdf

Stephan, B., Lee, I., & Kim, J. (2019). *Crashing the climate - How the car industry is driving the climate crisis*. Greenpeace East Asia & Greenpeace Germany

Toyota. (2022). *Sustainability Data Book 2021*. Toyota Motor Corporation. https://global.toyota/pages/global_toyota/sustainability/report/sdb/sdb21_en.pdf

UNFCCC. (2021). *Climate Action Pathway: Transport. Vision and Summary.* Marrakech Partnership. https://unfccc.int/documents/279262

United Nations Environment Programme. (2021). *Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered*. Nairobi

Volkswagen. (2021). *Sustainability Report 2020*. Volkswagen AG. https://www.volkswagenag.com/presence/nachhaltigkeit/documents/sustainability-report/2020/Nonfinancial_Report_2020_e.pdf

Volkswagen. (2022). *Sustainability Report 2021*. Volkswagen AG. https://global.toyota/pages/global_toyota/sustainability/report/sdb/sdb21_en.pdf

Weidema, B. P. (2022). *Comparison of the requirements of the GHG Protocol Product Life Cycle Standard and the ISO 14040 series.* Aalborg, Denmark: 2.-0 LCA consultants.

Wolfram, P., Tu, Q., Hertwich, E. G., & Pauliuk, S. (2020). *Documentation of the transport-sector model within the RECC model framework*. https://doi.org/10.5281/zenodo.3631938

Annexes

Annex I: detailed model calculation

Step 1: Historical data collection for 2010-2021

The following market data was collected and used for further calculations in the model. Detailed data sources can be found in the supplementary dataset.

- Total distance of cars driven (person-km or vehicle-km)
- Total car fleet
- BEV & PHEV absolute sales and BEV & PHEV sales share under IEA STEPS
- Total car sales estimated under IEA STEPS
- CO_2-intensity of electricity (in gCO_2/kWh)
- Carbon performance of cars (in gCO_2/km)

Additionally, the constants used in the model include:

- Average EV electricity demand of 0.199 kWh per km (EV Database, 2022)
- Car occupancy (constant over time, but different per country). Retrieved from NewClimate Institute et al. (2021) and Wolfram et al. (2020).
- Car lifetime (12 years). This value resulted from the average of the five regions.

Step 2: Modelling scenario 1 (STEPS)

As scenario 1 is based on the STEPS, we retrieved the projected absolute EV sales and EV sales shares for target years 2025 and 2030 from IEA STEPS data. Values for intermediate years between 2021 and 2030 were not directly provided and therefore interpolated linearly. Additionally, we model the fuel performance of cars based on most recent national fuel policies in annex IV. Total vehicle sales in 2030 were calculated from the IEA's projected EV sales and sales share (i.e. EV units in 2030 divided by the 2030 EV sales share). For India, we used an alternative car market projection to assess the impact of passenger cars only (Khan, 2022). Finally, for projections of the future car fleet size after 2021 we use annual growth rates of person-km projected in available roadmaps.

Step 3: Calculating new 2030 EV shares in scenario 2

When combining steps 1 and 2, new EV shares in the second scenario result from old STEPS shares and the additional shares from car companies. The calculation is provided below. The equation is based on the percentual difference between company targets and STEPS estimates per region combined integrated with the company 2021 market shares per region. Market shares were assumed to be constant at 2021 levels until 2030. The impact of EV companies BYD & Tesla was also included. Because these companies already have 100% EV sales, 2021 market shares of Tesla and BYD were directly added to regular car manufacturer impacts.

$$\sum\big((CM\ target\ 2030 - STEPS\ value\ 2030) * \ 2021\ CM\ market\ share\big) + market\ share\ Tesla\ \&\ BYD$$

*Example: Volkswagen has an European target of 70% EVs in 2030. In the STEPS, Europe has 38% EV sales in 2030. Volkswagen's target is (70%-38%) = 32% above STEPS. The company has a market share of 24.9% in the European market, meaning 32%*24.9% = +7.97% added to the EV share. The ten car companies together with BYD & Tesla add 37%. In scenario 2, the new EV sales shares in 2030 is 38+37 = 75% for Europe.*

These results are added to the model with the same calculations as scenario 1. Total car sales did not change for the first scenario, so we estimate absolute EV units based on these improved EV shares in 2030. The resulting emission calculation is explained in the final step below.

Step 4: Model calculations

The following calculation steps resulted in the final GHG emission reduction value:

1. Percentage of annual new car sales
   = (New sales/total car fleet)
2. Km driven of these new sales
   = [step 1] person-km/car occupancy)*
3. Km driven of the EVs. Here we also separate PHEV and BEVs and count half of PHEVs as conventional car and the other half as BEV.
   = [step 2] % of EVs)*
4. kWh use of EVs per km
   = [step 3] electricity demand of EV (constant at 0.199 kWh/km)*
5. Annual emissions from EVs
   *= [step 4] * national CO_2 intensity of electricity*
6. Carbon performance of new fossil fuel cars (in gCO_2/km)
   *= (CO_2 performance of cars * (1-EV share))*
7. Annual emissions from fossil fuel cars
   = [step 6] translated into $MtCO_2$.
8. Total annual emissions of the car fleet (= step 6 + 7)
9. Total GHG emissions over 12 years (car lifetime) of annual emissions in the model.

Steps 1-9 were replicated for the second scenario when EV shares had increased. In conclusion, the GHG emission reduction potential was defined as the emission gap between scenarios 1 and 2.

Annex II: full company reduction target list

Company	Target type	% Reduction	Target year	Base year
Ford	Use of sold products	-50%	2035	2019
Ford	Absolute scope 1 and 2	-18%	2023	2017
Ford	Absolute scope 1 and 2	-76%	2035	2017
Ford	Recycled + renewable plastics in vehicles	20%	2025	-
General Motors	Use of sold products	-50.4%	2035	2018
General Motors	Absolute scope 1 and 2	-71.4%	2035	2018
General Motors	Sustainable material new vehicles	50%	2030	-
Honda	Use of sold products	-90%	2051	2001
Honda	Total emissions	-100%	2051	2019
Honda	Use of sold products	-100%	2041	2001
Honda	Use of sustainable materials	100%	2050	-
Hyundai	Absolute scope 1 and 2	-26%	2030	2016
Hyundai	Absolute scope 1 and 2	-51%	2050	2016
Hyundai	Absolute scope 1 and 2	-45%	2030	2019
Hyundai	Absolute scope 1 and 2	-75%	2040	2019
Hyundai (Kia)	Absolute scope 1 and 2	-17.40%	2025	2016
Hyundai (Kia)	Absolute scope 1 and 2	-40%	2040	2016
Hyundai (Kia)	Use of sold products	-56.6%	2035	2019
Hyundai (Kia)	Absolute scope 1 and 2	-46%	2030	2019
Mercedes-Benz	Use of sold products	-42%	2030	2018
Mercedes-Benz	Use phase emissions (WTW)	-40%	2030	2018
Mercedes-Benz	Plants + purchases	-50%	2030	2018
Mercedes-Benz	Secondary/recycled raw materials share	40%	2030	-
Nissan	Logistics emissions	-12%	2022	2005
Nissan	Office + R&D sites emissions	-12%	2022	2010
Nissan	Dealer emissions	-12%	2022	2010
Nissan	Use of sold products	-40%	2022	2000
Nissan	Corporate emissions	-30%	2022	2005
Nissan	Manufacturing site emissions	-36%	2022	2005
Nissan	Use of sold products	-32.50%	2030	2018
Nissan	Total emissions	-5%	2030	2000
Nissan	Absolute scope 1 and 2	-30%	2030	2018
Nissan	Use of sold products	-90%	2050	2000
Nissan	Total emissions	-50%	2050	2000
Nissan	Manufacturing site emissions	-80%	2050	2005
Nissan	Life cycle emissions	-100%	2050	2000
Nissan	Absolute scope 1 and 2	-100%	2050	2018
Nissan	Share of recycled materials	70%	2050	-
Renault	Life cycle emissions	-25%	2022	2010
Renault	Use of sold products	-20%	2025	2019
Renault	Use of sold products	-35%	2025	2019
Renault	Use of sold products	-41%	2030	2010
Renault	Use of sold products	-35%	2030	2019
Renault	Use of sold products	-65%	2030	2019
Renault	Use of sold products	-50%	2030	2010
Renault	Absolute scope 1 and 2	-60%	2030	2012

Renault	Manufacturing site emissions	-50%	2030	2019
Renault	Parts & material supply chain emissions	-30%	2030	2019
Renault	Logistics emissions	-30%	2030	2019
Renault	Recycled material in new vehicles	33%	2030	2019
Renault	Recycled material in new vehicles	33%	2025	2019
Stellantis	Carbon intensity emissions	-50%	2030	2021
Stellantis	Total carbon footprint	-50%	2030	2021
Stellantis	Absolute scope 1 and 2	-75%	2030	2021
Stellantis (PSA)	Use of sold products	-18%	2025	2018
Stellantis (PSA)	Tank-to-wheel emissions	-30%	2025	2012
Stellantis (PSA)	Use of sold products	-37%	2034	2018
Stellantis (PSA)	Tank-to-wheel emissions	-55%	2035	2012
Stellantis (PSA)	Absolute scope 1 and 2	-20%	2034	2018
Stellantis (PSA)	Intensity scope 1 and 2	-30%	2034	2018
Stellantis (PSA)	Logistics emissions	-33%	2035	2016
Toyota	Tank-to-wheel emissions	-30%	2025	2010
Toyota	Tank-to-wheel emissions	-35%	2030	2010
Toyota	Tank-to-wheel emissions	-90%	2050	2010
Toyota	Absolute scope 1 and 2	-30%	2025	2013
Toyota	Absolute scope 1 and 2	-35%	2030	2013
Toyota	Absolute scope 1 and 2	-100%	2050	2013
Toyota	Logistics emissions	-7%	2025	2018
Toyota	Life cycle emissions	-18%	2025	2013
Toyota	Life cycle emissions	-25%	2030	2013
Toyota	Life cycle emissions	-100%	2050	2013
Toyota	Use of sold products	-70%	2050	2013
Volkswagen	Use of sold products	-30%	2030	2018
Volkswagen	Production emissions in plants	-50%	2025	2015
Volkswagen	Absolute scope 1 and 2	-50.4%	2030	2018
Volkswagen	Production emissions in plants	-50%	2030	2010
Volkswagen	Life cycle emissions	-30%	2025	2015
Volkswagen	Life cycle emissions	-30%	2030	2018
Volkswagen	GHG emissions per vehicle	-40%	2030	2018

Annex III: full company EV sales target list

EV target overview (2022) (Own analysis)	Target EVs	Year	Specific scope?
Toyota	**14%***	**2030**	
	49%*	**2030**	
	100%	2030	NA, CHINA, EU
Volkswagen	**22.50%**	**2025**	
	40%	2030	
	50%	**2030**	CHINA, US
	70%	**2030**	EUROPE
	50%	**2030**	
	100%	**2040**	
General Motors	**40%**	**2025**	**China**
	45%	**2030**	**US**
	70%	**2030**	
	100%	**2035**	
Stellantis	50%	2025	
	40%	2030	US
	70%	2030	EUROPE
	50%	**2030**	**US, INDIA, JAP**
	60%	**2030**	**China**
	100%	**2030**	**EUROPE**
Hyundai-Kia	100%	2035	EUROPE
	100%	2040	CHINA, US
	50%	**2030**	
	10%	2025	
	18%	2030	
	42%	2035	
	73%	2040	
	17%	**2026**	
	69%	**2030**	**EUROPE**
	58%	**2030**	**US**
	36%	**2030**	
{Kia}	16.6%**	2026	
	21%	**2026**	
	40%*	2030	
	52%	**2030**	
	78%	**2030**	**N-A, CH, EU**

Honda	**66.66%**	**2030**
	20%	**2030 JAPAN**
	40%	**2030 NA, CHINA**
	80%	**2035 JAPAN, NA, CH**
	100%	**2040**
Ford	45%	2030
	50%	**2030 USA + globally**
	66.66%	2030 EUROPE
	100%	**2030 EUROPE**
Nissan	18%*	2022
	75%	**2026 EUROPE**
	55%	**2026 JAPAN**
	40%	**2026 CHINA**
	40%	**2030 US**
	40%	**2026**
	50%	**2030**
Renault	50%	2025 EUROPE
	65%	**2025 EUROPE**
	90%	2030 EUROPE
	90%	**2030**
	100%	**2030 EUROPE**
Mercedes-Benz	25%	2025
	50%	2030
	50%	**2025**
	100%	**2030**

Annex IV: national targets

EV targets collected from IEA policy explorer (IEA, 2022d).

	Targets	Ambitions	National target/ambition
Current national policies	**EV Share**	**Target year**	
EU	**15%**	**2025**	**"Voluntary targets"**
	35%	**2030**	**ZEV, cars only (for vans, it's 30%)**
US	**50%**	**2030**	**ZEVs to be sold (PC + light trucks)**
	100%	2035	TARGET in NY and CA, AMBITION for MS & WA
China	15-25%	2025	Subnational targets for Ningxia, Tianjin and Shanghai
	40%	2025	Chongqing only, but LDV specific
	20%	**2025**	**NEVs in LDV and HDV sales**
	25%	**2025**	**NEV**
	40%	2030	NEVs
	50%	**2035**	**ZEVs only (100% of vehicles 'electrified')**
Japan	**20-30%**	**2030**	**BEVs and PHEVs**
	100%	**2035**	**"Electrified vehicles'.**
India	10%	2025	For Maharashtra state and includes two/three wheelers
	25%	2024	Only target, but only for Delhi city and all sales
	25%	2026	State of Assam only, BEVs in LDV sales
	30%	2030	State of Goa, buti ncludes 2/3W next to LDV
	30%	**2030**	**Only national ambition**
Other			
EV30@30 - EVI	**30%**	**2030**	**Includes China, India, Japan, 5 EU members + Norway & UK**
Eur. Commission Proposal	*100%*	*2035*	*Proposal, but may serve as de facto ICE phase out*

Fuel performance targets used in model scenarios based on the latest fuel performance standards (EPA, 2021; ICCT, 2020). Values in the table below are expressed in gCO_2/km. USA values include light-duty vehicles next to passenger cars.

Target year	2022	2025	2026	2030
EU		80.75		59.375
US	139.2	111.2	100.0	
India	113			
Japan				73.5
China		93.6		74.88

Annex V: in-depth steel and battery results per car company

Results were based on car company sustainability reports published before July 2022 (FCA, 2021; Ford, 2021, 2022; General Motors, 2021, 2022; Honda, 2022; Hyundai, 2021; Kia, 2021; Mercedes-Benz, 2021, 2022; Nissan, 2021; PSA, 2021; Renault, 2021; Stellantis, 2022; Toyota, 2022; Volkswagen, 2021, 2022).

Steel analysis

Toyota

In Toyota latest sustainability report, steel is never mentioned. Despite Toyota's long term goal of a zero emission life cycle by 2050, specifics on steel in the supply chain are not available in the report. Nonetheless, Toyota suppliers are more encouraged to actively reduce their emissions. The recent pledge to ask an annual 3% emission reduction from suppliers is one of the few quantitative targets for suppliers in particular and quite unique in comparison with most other car companies. Further information with example guidelines for suppliers are also openly available online. These guidelines distinguish separate guidelines for raw material suppliers, among which steel suppliers are mentioned. In conclusion, Toyota may be above average in transparency and setting targets for suppliers, but steel coverage is extremely limited in reporting.

Strengths (+)	**Weaknesses (-)**
Quantitative reduction target of 3%/year for suppliers	No mention of steel at all in reporting
Green supplier guide with detailed raw material supplier requirements (North America)	No SBTi approved targets yet

Volkswagen

According to Volkswagen, steel has been identified as a major focus of identifying CO_2 emissions in the supply chain and emission reductions. To this end, two specific measures are mentioned:

- Collaboration with the H2 Green Steel start-up for the Scania brand.
- Battery cases and wheel rims from green aluminium instead of steel for the VW passenger ID series.

The report includes entire chapters on supply chain responsibility and circular economy that presents examples of reducing aluminium, waste or water use, yet similar writings on steel policies are usually absent. The Volkswagen Group did not change its stance from the 2020 sustainability report and states that the Group is still "*in close communication with steel suppliers to switch to carbon neutral products*" (Mercedes-Benz, 2022, p. 41). In a separate 2020 report on raw materials, the company gives more information on their raw materials including steel. Volkswagen organized workshops and meetings with tier-1 steel suppliers, who also all responded and listed a few risks to be seen in this document. However, the information is likely incomplete as the risk assessment for steel supply chains is ongoing.

Strengths (+)	**Weaknesses (-)**
Separate information on steel policies and steel included as priority material	Risk assessment for steel still ongoing
Member of H2 Green Steel (through Scania) and indirect member of ResponsibleSteel (through the Drive Sustainability Initiative)	No separate attention of steel in circular economy chapter despite similar sections for aluminium, batteries or waste

Open information on steel with policies and examples	Few details within the examples of steel
High transparency on reporting and company responsibility, such as codes of conduct and management structures	No steel data reported in main reports

General Motors

The only mentions on steel in General Motors' most recent sustainability report include the impact of steel in their supply chain. The report does not contain more mentions of steel beyond this. General Motors has included much information on supply chain and material sourcing on the website, but steel is hardly mentioned at all in both the sustainability report and website. Nonetheless, all supplier requirements and policies on sustainability are covered and openly available online.

In the 2021 report, General Motors announced itself as new 2022 partner of Nucor's Econiq steel brand targeting net-zero carbon steel. It also organized its first Sustainable Steel Summit for employees, suppliers and Nucor in this year. General Motors is ambitious in their targets, but on steel policies there is still room to improve. More steel coverage may follow, as the announced collaboration with Nucor for producing net zero steel can become a substantial development.

Strengths (+)	**Weaknesses (-)**
Includes data on steel's impact on supply chain	Very little information on steel in reporting and website
Client of net zero steel initiative and new partner of Nucor's Econiq	No innovations or practical examples of steel usage
Large body of requirement documentation	

Stellantis

Because of the recent merger, initial findings on steel were separately reported by predecessors FCA and PSA until Stellantis published the first combined report in 2022. Before that, sustainability reports of the two previous companies differed greatly on steel coverage. Whereas FCA only mentioned steel twice (both in the context of recycling and consumption metrics), PSA had a relative high number of steel coverage in its report. Both companies also provided high levels of transparency on steel use data and associated environmental impacts in their respective reports.

The new company Stellantis provided information on supply chain practices through openly available guidelines and code of conduct. The associated web page further contains a mapping and auditing study of all direct battery suppliers and mining locations, which is unique in comparison with other companies. Unfortunately, this is until now only done for batteries. In the first sustainability report published under the Stellantis name in 2022, the mentions on steel are still scarce. It does not contain details on strategies or initiatives on steel beyond the ambitions to recycle steel properly and willingness to explore possible carbon taxes for steel and aluminium from an European Commission proposal. Possible strengths are the coverage of high-tensile steel implementation as lightweighting option and data on the estimated impact of steel as featured in PSA's report.

Overall, there is much information with high transparency on Stellantis suppliers, but it is still too general to say something on (for instance) steel or even raw material suppliers in particular. Despite the merger Stellantis has not provided more information on steel compared to its predecessors. For now, the most info on steel is in PSA's 2020 Sustainability Report, which includes steel data, strategies for steel recycling and examples of improved steel practices within a specific Peugeot model.

Strengths (+)	Weaknesses (-)
High transparency on supplier choice and requirements	Low steel coverage and no details in first Stellantis report
Public refiner and mining lists	Too general on steel/raw materials in provided documents
Published detailed data on steel use and impacts (both FCA and PSA)	

Hyundai-Kia

In Hyundai's sustainability report, the only relevant mention of steel refers to the usage of high-strength steel plates as example of weight reductions, similar to PSA. For Kia, the mentions are about the steel consumptions from the latest years, which is unique compared to other companies. The steel company directly linked to Hyundai Motor Group, Hyundai Steel, is working on less emission-intensive pathways as member of the Korean Green Steel Committee and the Responsible Steel Initiative. In the SBTi database, Hyundai supplier Hyundai Mobis is also included, but the car company itself is not mentioned.

In its carbon neutrality white paper, Hyundai has mentioned ambitions for a lower carbon-intensity supply chain. Hyundai proposes a program where partners will be chosen to work on reducing emissions and asking supply chain to be carbon neutral. The program also includes categorizing and measuring emissions from 400 suppliers and joint solutions for recycling for raw materials specifically. However, there is no accurate time scale linked to these plans, which makes it uncertain if and when these plans will be implemented in actuality. Finally, supplier regulations are available online, but do not contain additional explanations or reduction ambitions apart from the requirements itself.

Strengths (+)	Weaknesses (-)
Clear disclosure of steel data, both raw and scrap	Few attention on steel at all in sustainability report
Separate reduction targets from suppliers Hyundai Steel and Hyundai Mobis	Few information for suppliers (e.g. code of conduct)
Hyundai Steel in Responsible Steel Initiative	Supply chain strategy formulated, but not implemented yet

Honda

Similar to Toyota, Honda does not mention any steel policies in sustainability reporting, but has recently announced a clear quantitative reduction target for its suppliers. Honda requires suppliers to annually cut 4% of their emissions from a 2019 baseline towards the long-term zero emission target in 2050. Honda said it is the first carmaker to have a long term vision communicated with their suppliers too. This can be a strong measure, but further strengths of Honda's vision on steel and its suppliers have not been found yet.

Apart from the emission reduction targets of the company, general reporting is also unclear about subjects such as sustainability and supply chains. For instance, Honda's supplier requirements are externally available through the sustainability report and are very brief on material policies without any mention of steel.

Strengths (+)	Weaknesses (-)
Quantitative emissions reduction target for suppliers (4%/year)	No relevant mention of steel in sustainability report or elsewhere
	No SBTi approved targets
	Limited information from presented supplier requirements and website

Ford

Ford's sustainability report for 2021 confirms current recycling of steel and aluminium in vehicle production, but does not include further policies on steel or any material data. Ford's major strength, however, is the extensive information on supplier requirements. The ambition level for suppliers is also relative high, as they are asked to report scope 3 emissions and create individual GHG reduction targets. Responsibility of material sourcing from the company is also legislated and documented well (for instance by inclusion of various initiatives), but mentions of steel are generally scarce.

Strengths (+)	Weaknesses (-)
Strong supplier requirements, explicitly requiring scope 3 reporting and target creation	Few mentions of steel in reporting and website

Nissan

The most important feature on steel policies within Nissan is the focus on ultra-high-tensile steel. The sustainability reports gives examples on the usage and emission reduction of this particular steel type. Furthermore, Nissan arguably provides the most information on recycling efforts, including mentions of steel in closed loop recycling at the end-of-life stages of vehicles. Similar to Volkswagen, the sections dedicated to steel policies next to comparable policies for waste and water are not there. The guidelines for suppliers are categorized per supplier type in a detailed and openly available document, in which the requirements include a link with the company's overall reduction targets.

Strengths (+)	Weaknesses (-)
Examples of initiatives for steel replacement and recycling in models	No steel data in resource data chapter, only raw materials
Specific requirements for raw material suppliers in guidelines	

Renault

In general, Renault has a relatively strong coverage of steel in its policy. Despite not covering steel in the sustainability report, it is extensively covered in the comparable universal registration document. Here, two specific examples of technology innovations on steel are mentioned. Due to their alliance, Renault & Nissan share a number of requirements for suppliers, which means that Renault also distinguishes raw material requirements and is involved in various material sourcing initiatives like Nissan. When comparing the documents, Nissan often has more detailed and recently updated material available than Renault's versions. Furthermore, similar to Stellantis, Renault has done a mapping and auditing study on refining sources, this time for cobalt. Most importantly, Renault's website includes percentual reduction targets aimed at the supply chain and is so far the only of the ten companies included in this research to do so. Renault has a target for parts and material in the upstream supply chain of -30% in 2030. Steel is one of the six components and materials included in this target, that together account for 90% of the emissions from Renault's purchased materials.

In conclusion, Renault is one of the better performing companies here, with requirements for raw materials, a brief mention of their steel consumption and a reduction target. Nevertheless, the impact of steel in particular within the company's ambitions is still not clear despite being the only company even including steel in reduction targets. Furthermore, the company chose to present information on steel outside of the sustainability report, which is a weakness from a transparency viewpoint.

Strengths (+)	**Weaknesses (-)**
Specific requirements for raw material suppliers in guidelines	No mention of steel in sustainability reporting
Large body of supplier documentation available	No specific information on steel suppliers specifically
Quantitative emission reduction target for steel in supply chain	

Mercedes-Benz

The number of steel mentions in sustainability reporting is high at Mercedes-Benz. The 2020 report includes data on steel within an example car model and explains that Mercedes-Benz made a risk assessment in which steel was identified as crucial material to limit supply chain emissions. It is specifically mentioned how steel has been integrated into the strategies for choosing suppliers which further led to new targets to be included in questionnaires. However, the results and tools associated with this risk assessment are not openly available or included in the report, which means that information on this process is limited. Similarly, the available sustainability standard for suppliers do not contain much information in comparison with other companies.

Nevertheless, we defined Mercedes-Benz as one of the more ambitious companies in this company selection for steel. The Group is part of both the Responsible Steel Initiative and the H2 Green Steel Initiative. The company aims to use Green Steel in models from 2025 onwards already and is simultaneously working on letting suppliers sign an agreement to produce carbon neutral products in the future (unknown target year). After publication of the 2021 sustainability report, steel strategies were covered in a separate paragraph where collaboration with steel suppliers are mentioned together with quantitative estimations. The report explains three new steel collaborations in more detail:

- Big River Steel, which reduces 70% of steel emissions through scrap recycling and renewable energy.
- Salzgitter Flachstahl GmbH, which already led to a 60% reduction for flat steel products resulting from scrap metal use.
- SSAB, which is developing CO_2-free steel. Volkswagen expects the first prototypes this year.

These major updates in combination with a very ambitious company-wide carbon neutrality target in 2039 and participation in two separate Steel Initiatives make Mercedes-Benz one of the more ambitious companies on this topic.

Strengths (+)	**Weaknesses (-)**
Member of both Responsible Steel and H2 Green Steel	Fewer information on the steel risk assessment and the supplier requirements on steel

Steel integration into strategy, supplier choice and targets	Very basic supplier requirements
Most mentions of steel in reports and clear ambitious future plan	
Multiple ongoing collaborations on CO_2-free steel	

Battery analysis

Toyota

Toyota's mentions on batteries in the sustainability report are mostly aimed at re-using or recycling initiatives as one of its five major climate mitigation strategies. More specifically, Toyota's Car-to-Car recycle project includes ambitions for an operating 3R (reduce, reuse, recycling) strategy on batteries in four of five top car markets assessed in this research, as well as an optimal way of collecting and detoxing them. In the period 2017-2021, seven of these battery facilities have been introduced and promoting organizations for these 3R strategies have been set up. In the near future Toyota targets fifteen end-of-life treatment facilities, allowing for further development.

Apart from establishing a proper recycling system, further quantitative targets are not yet presented. All mentions on batteries fall under Toyota's recycling targets instead of the company's three main zero-emission challenges for 2050. In comparison, this section includes clear targets about the use of recycled plastics and reduction of general plastics, but this sections' battery ambitions are presented in more general terms for collecting and reuse. In terms of data disclosure, Toyota includes data on the (increasing) amount of recycled batteries and potentially crucial cobalt audit results. There are also LCA results where a 10% emission reduction has been achieved, albeit for HEVs only. This introduces a unique point for Toyota which is their focus on hybrids in general. It must be noted that almost all battery mentions are specifically for HEV batteries. With HEVs accounting for 97% of total EV sales in 2020, it is clear that the NiMH-batteries within these vehicles remain the core of Toyota's battery strategy (as opposed to the lithium-ion options from BEVs that are widely used today).

More information on batteries is available through additional sources referenced directly in the sustainability reports, such as the 2021 media briefing on batteries and carbon neutrality. Battery strategies are explained in more detail here. First of all, Toyota's current ambitions are focused on 'enhancing' NiMH batteries and 'establishing' LIB technology, again suggesting a clear NiMH preference. In this strategy, the desired amounts of ZEV until 2030 include a significant increase in BEV and FCEVs, but HEV cars will still be the most dominant ZEV type. On the other hand, in its presented timeline Toyota will also use and improve LIBs in the near future and invest in solid-state battery (SSB) research, providing interesting technology examples and data in the media briefing.

Considering Toyota is an extremely large car seller yet still has so few BEV sales, there can be criticism about maintaining both HEV and NiMH strategies from an emission standpoint. Automotive reports already suggested a limited effect of hybrid vehicles (IIGCC & 2DII, 2020; Stephan et al., 2019). Toyota's seems to have considered LIBs only recently, while other carmakers in this analysis have focused on LIBs for longer periods and often use them as a standard practice already. Finally, the company acknowledges the rise of battery demand and has a battery supply target in its reports, but the most important target that covers BEV batteries is focused on a 30% cost reduction rather than environmental impacts.

In general, the sustainability report clarified that Toyota wants to be a frontrunner in developing more efficient batteries. Additional sources contained more detailed plans how to achieve this, but key future ambitions are currently limited to research & development or cost reductions. Considering the current state of BEV sales, we argue that Toyota needs to accelerate its battery and EV strategies to enable significant emission reductions that would align with their market position as top car seller, most notably stepping away from HEV-only practices.

Strengths (+)	**Weaknesses (-)**
Major plans regarding establishment of battery 3R strategies in top markets in one of Toyota's key challenges	In sustainability reporting, strategies are mostly aimed at recycling batteries
Serious consideration and research & development towards advanced LIBs and SSBs in the future	Details on battery strategies only appear in additional documentation
	Reduction targets for batteries are not aimed at emission reduction specifically (but rather cost and consumption power)
	BEV and even PHEV are still heavily underrepresented in favour of HEVs, leading to conservative NiMH batteries as main focus for Toyota

Volkswagen

Volkswagen is planning on a significant increase in battery capacity following the expected rise of EVs. The latest sustainability report provides multiple examples of newly planned battery plants, such as leading to a new lithium-ion battery gigafactory in 2024 in collaboration with Northvolt AB. With the aid of Volkswagen's newly built battery research facility, the company promises to launch a new battery cell in 2025, although it is not immediately clear what innovations this cell will have. The battery strategies are represented fairly well within the Group's NEW AUTO strategy, as one of twelve core strategies is particularly dedicated to batteries and battery cells. The Cell and Battery Initiative is mentioned as a tool to develop this together with suppliers. In addition, the Europe-based CEO Alliance is mentioned, where battery production is included but does not seem to be the main focus of the alliance. Nonetheless, Volkswagen's participation could add an extra layer of responsibility and stimulate other car companies to look at the European regulations on batteries.

Similar to the steel analysis, there are mentions of obligatory use of renewable energy for battery manufacturing suppliers, leading to lower battery manufacturing emissions according to Volkswagen. This regulation has been expanded for all new supplier contracts of tier-2 intermediate battery production materials. Similarly, direct battery suppliers are obliged to disclose information from mining to manufacturing of crucial battery materials like cobalt and lithium. These measures were strengthened with multiple initiatives seeking to ensure responsible supply chains and overall transparency. The transparency in the sustainability report is also sufficient, as Volkswagen provided various key emission indicators that gave an indication of the current developments. The first battery recycling facility opened in 2021 (albeit on small scale), where batteries can be produced with reduced emissions by avoiding blast furnace processes. Volkswagen targets a 90% recovery rate of critical materials and estimates that 1.3 metric tons of CO_2 emissions per (62 kWh) battery can be avoided due to implementing green electricity and material recycling. This is roughly equal to the production and logistics emissions for a new ID.3 car model.

Finally, in comparison with its competitor Toyota, Volkswagen does not seem to include many technological details or planned innovations that must take place in the announced facilities. Future battery types, practical examples of lightweighting and battery use in different vehicles were not covered extensively in sustainability reporting. Volkswagen's strategies may be more ambitious, yet it is not always clear how these strategies will shape the coming years.

Overall, Volkswagen is one of the frontrunners and seems to take responsibility for their current position as top car seller. This is reflected in the involvement of many initiatives and targets that often surpass the national regulations of the EU, its most dominant market. With the new measures for suppliers the ambitions can already lead to reduced emissions from the supply chain and battery production rather than use and recycling measures. In conclusion, the ambitions are high, the information about these ambitions is – similar to many others – not always clear.

Strengths (+)	**Weaknesses (-)**
Product-specific guidelines for battery suppliers to use renewable energy and disclose supply chain processes	The sustainability report contains no examples of new batteries and innovations accompanying announced plans
General sense of responsibility in plans to build upon current market leader position in e-mobility with lower emissions	Battery strategies are mostly focused on production strategy and less on design, types or vehicle type distinction
Facility for recycling and emission avoidance including quantitative reduction potential estimates	
Part or initiator of multiple projects and initiatives, e.g. for lithium	

General Motors

General Motors has four major battery manufacturing facilities planned for this decade which will be a record investment. Moreover, a special battery innovation centre (which is currently being built or has just finished) has been announced. General Motors also provides a visualization of all the new facilities they have planned together with their investments to align with their absolute EV targets.

These strategies are currently very much focused on financials. One of the few quantitative indicators on batteries is the claim that 100% of all batteries returned to the company are refurbished, reused and recycled. Generally, the sustainability report has a very good breakdown and data availability of GHG emissions, recycled components and material or supplier engagement. The parts on batteries may be underwhelming in comparison, only very rarely giving a reduction potential. There is one example mentioned with a 30% lower carbon footprint for battery material production due to strategic sourcing of recycled materials, but these processes and their potential uses are not explained further in the report.

EV strategies are very dominant in General Motors' latest report and announced future. One unique aspect for the company is the reduction of battery manufacturing emissions by introducing their Ultium EV platform. With this platform, the new Ultium battery type is claimed to be lightweight and the company is working to create the new battery cells through a joint venture with LG, LLC Ultium Cells. The report features a link to a short video with more details on the battery revolutions. Promising lightweighting features include the significant decrease (70%) of cobalt in Ultium batteries through aluminium substitution and a 60% energy capacity increase due to space-efficient cells, both featured in this video.

Similar to Volkswagen in Europe, General Motors includes a number of US-based initiatives to further improve battery recycling and engage with suppliers. These included a collaboration with the US government through the Advanced Battery Consortium and online information tools for suppliers on the most efficient applications of returned batteries. On materials in general, steel and batteries (together with aluminium and plastics) are integrated in the company's commodity management plan which in line with the Responsible Minerals Initiative. The information and engagement with suppliers is also positive, for instance in providing more details on which suppliers and companies General Motors has agreements with. However, this car company still lacks quantitative and binding reduction targets for these suppliers.

General Motors frequently includes precise amounts of recycled materials and emission data in their sustainability report. Combined with promising recent Ultium developments, lightweighting options are promising for this company. On batteries in particular, General Motors will undeniably invest heavily, but we do not know whether these investment can fulfil all expectations from an emission reduction perspective as the current strategies are still dominated by financial terms. The Ultium platform can strengthen their position in the market, but the lack of BEV and PHEV mentions also stands out. The level of detail that General Motors provides for their planned battery facilities, new technologies and suppliers is not reflected in data on sales projections, vehicle types, weight reduction and above all, emission reduction potentials.

Strengths (+)	**Weaknesses (-)**
Very strong existing battery recycling infrastructure	No additional information on differences between vehicle types (BEV vs. hybrids)
Large share of sustainability report is dedicated to battery and EV advancement with technological details	Battery strategies mostly focus on financial data (e.g. investment data and costs instead of potential emission reductions
Unique new Ultium battery with lower weight, higher energy density and lower use of cobalt.	

Stellantis

Like other companies Stellantis announces new factories before 2025 to improve overall battery supply and an increase in battery capacity in 2030. Especially in Europe and North America, Stellantis is making efforts to become a leader in battery cells and modules. The company announced new factories and joint ventures with Samsung and LG, where significant extensions of battery supply are expected in the next few years. Simultaneously, Stellantis' ambition is to develop a high energy-density battery as well as an alternative without nickel and cobalt by 2024. These technologies are estimated to cost 20% less than current battery types. In addition, the company hopes to have introduced commercial solid state batteries in 2026 and become a dominant player in this market.

The aforementioned auditing system for battery supply chains is extensive, with annual source mapping and participation in various initiatives like the Responsible Minerals Initiative. Stellantis claims a 4% increase in usable energy due to its battery management system, but unfortunately this system is not explained further in the sustainability report. One promising option for lithium specifically is the production of lithium hydroxide through geothermal energy rather than fossil fuels, which must also be operational from 2026 onwards. The current recycling metric is 69.3% for Li-ion and 83.8% for NiMH from ex-PSA brands in Europe. Battery repair and expertise centres are already in use, but end-of-life ambitions are not yet defined in detail. Stellantis formulates percentual targets for other topics, such as production with a minimal percentage of green materials, but for batteries this is not the case. For example, the current material target aims to have 'at least one battery optimalization solution' for each high voltage battery. However, the company provides more detail on the desired battery technologies and their specifications such as energy density levels. Furthermore, Stellantis is one of the companies with more extensive information on end-of-life treatment, for instance describing the current high-voltage battery 3R system and providing precise data about second-life battery uses.

Overall, Stellantis has dedicated various portions of their sustainability reports to batteries, with a high number of battery mentions and basic descriptions of the planned future. Information in the large sustainability report is often repetitive or too generic. Nevertheless, Stellantis is one of the more transparent and ambitious carmakers on battery strategies and has launched initiatives in many of the relevant topics. Ambitions such as introducing cobalt-free and solid-state batteries within the next five years are promising, and could provide lightweighting and design improvements on top of EV introduction. Furthermore, the company is sufficiently transparent about their current projects, partners and joint ventures in this category. However, like other companies, the link with emission reductions is not fully established, complicating possible predictions on how these ambitions will affect environmental performance. Short, medium and long-term targets for batteries often focus on finding solutions for key markets instead of realizing quantitative reductions within these solutions, meaning that reduction potentials remain limited. Therefore, Stellantis is ambitious, but must continue to improve battery targets in comparison with other solutions mentioned in its sustainability report.

Strengths (+)	**Weaknesses (-)**
Available data on battery recycling rates and recycling practices	Other quantitative data (e.g. manufacturing data and performance of new technologies) remains limited
Transparent and informative about current and planned projects, initiatives and collaborations	Fewer mentions of batteries in the context of emission reductions
Ambitious scaling of innovative battery technologies already planned for relatively short term (2024 cobalt free, 2026 SSB)	Repetitive and generic information on batteries in sustainability report

Hyundai-Kia

Most of Hyundai's and Kia's battery strategies is integrated into their patented EV platform E-GMP (Electric Global Modular Platform), allowing for the development of higher capacity batteries and vehicle range. According to Hyundai-Kia, this platform will make other EV developments easier to implement. Part of the strategy is focused on consumers and providing them with solid EV infrastructure and a battery subscription system. Hyundai-Kia hopes to add maintenance and recycling components to this system as well. Nonetheless, the only battery consideration mentioned within the environmental scope is the introduction of the energy storage system (ESS) to retrieve and reuse second-life batteries from EVs. The company wants to tackle the gap in between first EV battery use and end-of-life recycling, targeting the range in between 80% and 50% of the original battery's performance and improving the circular economy of its components. This system currently has a pilot with some major energy partners and suppliers in Korea, but Hyundai-Kia wants to expand the current (pilot) projects to Europe and North America.

Hyundai states in its sustainability report that it has "*established strategies to reduce the GHG emissions levels of its supply chain, including raw materials, while using recycled materials and promoting the recycling and reuse of waste EV batteries*" (Hyundai, 2021, p. 44). The report does not contain many examples and explanations for these ambitions, except for the statements that the ESS can reuse critical materials and that Hyundai asks its suppliers to be responsible with minerals. There are few relevant and practical mentions on battery and raw materials strategies, especially in comparison with the companies assessed before.

Finally, Hyundai has created an initiative to select suitable start-ups for EVs to encourage investment into new battery innovations. In the presented EV timeline, the new generation of EVs with SSBs should be mass produced by 2027. Again, the sustainability report limited to general comments on future commitments without targets or requirements to make this happen effectively. Similar principles apply in Kia's report, which was mostly on the E-GMP system and a focus on developing SSBs for the future fleet. The only statement on possible reduction potentials in these two reports includes the specific effect of the new SiC semiconductor in the new Kia EV6 model, that leads to an increased driving range of 5% (the equivalent of saving 1.5 batteries).

In comparison to other car companies, Hyundai-Kia has a relatively low number of battery mentions in sustainability reporting. This company relies on two particular measures. First, the patented E-GMP platform that can have multiple developments in the future, albeit not all relating to reducing emissions. Second, Hyundai-Kia has an extensive battery recycling & recovery system planned, which seems to take almost all attention on battery research. Both Hyundai and Kia seem to fully focus on developing SSB in the near future rather than further innovating existing batteries. However, apart from the specific E-GMP and ESS systems, this company is significantly weaker in covering the other aspects of batteries, such as innovation centres, technologies and supplier commitments.

Strengths (+)	**Weaknesses (-)**
Created E-GMP platform and ESS recovery system to enable EV development and increase battery life before recycling	No mentions of technologies/innovations, data or reduction potential estimates beside ESS and E-GMP
Clear and ambitious SSB target formulated to replace LIBs (2027)	Low transparency on future strategies and investment planned or current data disclosure

Honda

In Honda's sustainability report there are almost no relevant mentions of batteries. This report mostly contains very generic statements, such as the ambition to make batteries swappable and to recycle them better. Whereas swappable batteries are still partly covered in the report by Honda's Mobile Power Pack system, recycling strategies can only be linked with the ultimate long-term goals of 100% recyclable materials and net-zero practice for 2050. The road towards this goal is not addressed properly.

A stronger point is that Honda specifically addresses solid state battery research. In 2021, the first verification and demonstration processes have started, and Honda hopes to have introduced them in the period 2025-2030 with accelerated research. Remarkably, this is the only section in the sustainability report where these batteries are addressed, even though they could become crucial for Honda's future. The Power Packs and battery utilization return in the larger eMaaS concept of connecting electricity and mobility with renewable energy. Although the report includes a schematic figure of this concept, the characteristics and strategies associated with this system are barely addressed.

In conclusion, Honda's sustainability report has a very poor battery coverage with almost no information to analyse. The company wants to use portable batteries and improve recycling, but there are no details to be found. Similarly, the SSB research and eMaaS concept that can reduce environmental impacts of batteries are mentioned without crucial additional information. The sustainability report provides insufficient information about Honda's strategies on batteries and fails to cover almost all aspects on batteries that were covered by the other car companies.

Strengths (+)	Weaknesses (-)
Research and planning of all-solid-state batteries as alternative for introduction somewhere in 2025-2030	Poor battery coverage in SR, only including basic information on strategies and generic statements
	No details of strategies, innovations or announced assets on batteries

Ford

Like General Motors, Ford announces a large investment (50 billion USD) in the next five years and wants to double EV capacity for next year. In Ford's action plan, the planned targets and investments on batteries are available and form a large part of the overall strategy. The company sees electrification and batteries as one of the highest priorities, both for Ford itself and its suppliers. As second-highest EV seller in the US, the goal is to challenge the top position.

Ford is transparent about future projects and battery factories that will be built with partner SK Innovation, such as the dedicated Ford Ion Park and BlueOval SK Battery Park. It became clear the company heavily invested in LIB production and recycling for the short term. Initiatives for electrification are also included for European countries and China. The Ion Park will serve as research and development facility to improve battery production. Finally, Ford plans more research on SSB batteries and has invested in an industry-leading SSB producer company. More specific applications of new techniques are still absent. The report features many practical developments for specific Ford models, but batteries are not always covered in these sections.

The efforts on recycling still appear ongoing and not yet realized. The report continuously mentioned that Ford is working on including battery recycling into their domestic recycling strategy. Ford estimates to cover up to 95% of critical battery materials resulting from partnering with Redwood Materials. Battery materials also feature in the new material audits for nickel, cobalt and lithium started in 2021. This battery supply chain audit is explained further in Ford's human rights report, making it one of the more transparent carmakers in this category. Ford and Redwood can certainly build a strong battery recycling system, building on Ford's current position as largest automotive aluminium recycler and its current value of 85% recycle and reuse of vehicle materials. However, information on batteries is often repeated throughout the report and limited to the general pledges for investment and collaborations. Therefore, based on the sustainability report alone it is still unclear how some of Ford's pledges work out.

Ford has dedicated a significant part of their budget and ambitions dedicated to EV and battery strategies on their goals towards 2050. Considering the short-term planned production and innovation centres on LIBs and later SSBs, they can be crucial for Ford's EV market and battery development. Finally, Ford has relatively high existing recycling data and supply chain engagement. Therefore, Ford has a large potential for battery strategies considering their current market position and ambitions, but there is fewer information about practical battery applications, making it harder to estimate how Ford's electrification campaign compares to other car companies.

Strengths (+)	Weaknesses (-)
Detailed strategies for battery material recycling and auditing/disclosure (Ni, Co, Li)	The battery recycling strategy could have more details and still needs updating

High value and transparency on future battery investments	And more examples of innovations and technologies of battery application or research.
Decent coverage of materials in reporting	Repeated info or statements

Nissan

Battery strategies make up two of four main strategies presented towards carbon neutrality in 2050 in Nissan's sustainability report. One quantitative example of battery improvements can be seen in the number of battery cells per vehicle, as the new Nissan Leaf E+ has 288 cells per vehicle in comparison to 192 in the earlier Leaf model. Although this is not directly about CO_2 emissions, it estimates the possibilities on lightweighting and better energy density in Nissan vehicles. Nissan's innovation strategies are aimed at batteries with lower cobalt shares and SSBs. Battery costs are targeted to reach ICEV levels of profitability by 2030. In the latest 2030 vision, the company announced the ambition to introduce SSB in 2028 after a Japanese pilot phase planned for 2024. These are positive developments, but the targets and their details are generally weaker than other car companies. In Nissan's short term action plan for 2022 batteries are only featured slightly, except for a general expansion of the EV reuse system promoted in the previous action plan.

To electrify its vehicle line-up Nissan has develop a unique E-Power powertrain for the new generation of hybrids. This technology can become an additional option for EV innovations, requiring a smaller battery and reaching above-average efficiencies (as argued by comparative LCA results in the report). However, even with E-Power, EV-specific parts still have more manufacturing emissions than conventional cars. These improved hybrid characteristics may provide a better transition pathway from ICEVs towards EVs for the automotive industry, but Nissan should simultaneously cover BEV development.

In its third strategy Nissan relies on a 'battery ecosystem' predominantly aimed at reuse and recycling. Since 2010, Nissan has had the joint venture 4R Energy Corporation to stimulate more reuse and second life of LIBs, with the first specialized recycling plant opening in 2018. The current state of this battery system is not specified in the report, but Nissan has had a head start in supplying batteries to secondary users compared to companies that only recently announced comparable facilities. In addition, the report includes practical usages of EV batteries outside the automotive industry and targeting grid electricity (e.g. Nissan's 'Blue Switch Program'). One major manufacturing project is the new 2021 EV hub in the UK. This billion-dollar investment was created to optimally combine battery production with 100% operational renewable energy and energy storage use from second-life EV batteries. Nissan already announced the expansion of EV hubs to key markets China, Japan and the United States in a recent update. Various other carmakers have presented ambitions for EV hubs and infrastructure, but the combination of technologies in this facility can indeed become a 'blueprint' for the car manufacturing industry, as Nissan also pledges to share this knowledge globally.

One of Nissan's strengths is the detailed section on weight reduction measures. While this chapter is more on strengthened steel than batteries, it includes estimations of closed-loop aluminium recycling that could save more than 90% of energy in the new Qashqai model. Moreover, Nissan claims weight reductions resulting from the E-Power system of 15% for the motor and 30% for the inverter, while simultaneously increasing output by 6%. Emission reductions are also featured in LCA results, showing 18% and 27% CO_2 emission reductions of two E-Power car models compared to conventional ones.

Nevertheless, Nissan also included repetitive and less relevant mentions of batteries. Specifically the introduction of the 4R company and their associated work is constantly repeated throughout the sustainability report. Nissan consistently uses the general term EVs without mentioning vehicle subcategories. There is only one page of information on PHEVs, and BEVs are not specifically mentioned. Considering the focus on the (hybrid-based) E-Power, it is remarkable that the difference between BEVs and hybrids is not explained further.

In conclusion, an assessment of Nissan's battery strategies is challenging because of significant advantages but also major pitfalls. For the presented strategies, Nissan does not hesitate to provide details, examples, systems and even sporadic quantitative supporting data. Furthermore, it has a promising unique powertrain technology with improved environmental performance and an ambition EV hub for future development. However, these plans can also limit reduction potentials, as E-Power focuses on hybrids while BEV coverage or new battery developments seem to be underrepresented in Nissan's latest report.

Strengths (+)	**Weaknesses (-)**
Multiple opportunities to expand EV and battery use described in sustainability report	Largest focus on end-of-life strategies (such as 4R) instead of emissions from battery production and supply chains
Major campaign on battery recycling and using electricity elsewhere (e.g. vehicle-to-grid)	Repetitive and less relevant information given on batteries throughout report
Unique Nissan powertrain technology with lightweight and efficiency potential in EV	E-Power system covers hybrids only, BEVs not mentioned specifically
Relatively strong disclosure of relevant data, e.g. LCA results and weight reduction estimates	

Renault

Renault has dedicated an entire strategic action to deploying batteries. The battery strategy in the sustainability report includes measures to stimulate low emission battery production, maintenance, recycling and second life usage. From the reduction target analysis it became clear that Renault is the only car company where battery production is covered by the company's quantitative upstream emission target for parts and materials. Renault adds a battery-specific target of reducing battery manufacturing emissions by 20% in 2025 and 25% in 2030 for new models. Furthermore, Renault has set another quantitative target of reusing 80% of nickel, cobalt and lithium in new batteries before 2030. The final key strategy covers second-life strategies such as vehicle-to-grid.

Renault is part of one battery-specific alliance, the Global Battery Alliance. This alliance aims to create better battery value chains, for instance by introducing battery passports improving data reporting and resource efficiency. Renault has set up more collaborations for metal or battery material recovery and treatment. However, more information on the processes involved in these initiatives is needed: the information in sustainability reporting is mostly limited to one summary page with minimal explanations elsewhere. As explained in the steel analysis, Renault uses a more extensive universal registration document for additional explanations. This lowered the sustainability report's transparency compared to other car companies, who generally presented these explanations in only one publication. The announced spendings on battery research and development are also not supported with information on battery types or innovations.

As mostly European-based company, Renault is the first carmakers in this analysis to talk about the EU's draft regulation to set carbon footprints thresholds for batteries in 2027. This regulation formed Renault's argumentation for the targets and might accelerate battery emission reductions for this specific region. Finally, the company added LCA results between a conventional and new electric Renault model in the report's annexes. These results showed that the electric ZOE model can lead to a GHG emission reduction of 28% compared with the Clio V ICEV when assuming the average European electricity mix. This difference increased to 64% in case of the French electricity mix.

In conclusion, Renault seems to take a high amount of responsibility for batteries by implementation of multiple battery reduction targets and a specific alliance that puts them ahead of other car companies. Particularly on battery technologies, investments and innovations, information is often not provided in the sustainability report, but is available through additional explanatory videos and documents. Nonetheless, it is clear that battery strategies form one of Renault's key future policies.

Strengths (+)	**Weaknesses (-)**
Quantitative emission reduction targets for battery production in new models	No details on battery innovations and application of recycled products in EVs
Action plan dedicated to various battery life cycle stages	Lower disclosure on expenses and planned facilities dedicated to battery or EV production
Report includes LCA data on emission reductions from new electric models	Limited coverage in sustainability report without additional documents

Mercedes-Benz

Battery ambitions from Mercedes-Benz have recently been integrated into the latest EQ series, which already has major improvements in cobalt shares and emissions from material production. The company simultaneously focuses on retrieving sustainable materials from their suppliers together with new battery or vehicle types. For instance, Mercedes-Benz promises to only buy CO_2-neutral battery cells from their partners, and estimates a 30% reduction in emissions from this measure. New batteries have already reached cobalt shares under 10%. Future batteries will increasingly use nickel to replace cobalt until post-LIB batteries are available.

Mercedes-Benz acknowledges that most LIB-based EVs currently produce twice as much as conventional cars and wants to change that to reach climate neutrality in 2039. The company is transparent on disclosing the plans for new factories and increased battery supply including their current location and development status. There will also be a battery-specific facility for the EQ from 2025 onwards and a total of eight overall battery production factories. Currently, 70% of batteries are reprocessed.

A separate paragraph on battery development in the sustainability report states that Mercedes-Benz is not only looking to reduce the critical materials but also to retrieve them from audited mines (following their audit studies and the standard from the IRMA organization on responsible mining). Beside two agreements with battery suppliers, the first research and development attempts for SSB and LIB energy density improvements are also ongoing. The company even stated that the first SSB prototypes are to be tested in 2022. On recycling, Mercedes-Benz admits that processes must be improved for the modules. Planned battery recycling facilities and factories are already planned until 2023 and recycling rates already exceed policy quotas. Additionally, a strong point of the sustainability report is the transparency on vehicle CO_2 performances, including voluntarily reporting that already aligns them with Europe's future policies for this topic. This is also the case for the raw material information in the supply chain.

Because Mercedes-Benz has an ambitious 2039 carbon neutrality target they need to align their strategies accordingly. Significant emission reduction have already been achieved in EQ models by tackling the procurement of battery materials, especially through partners & battery suppliers. Mercedes-Benz combines this with transparency on supply chains, quantitative reduction data and future plans. The material and supplier perspectives are promising, and the amount of planned battery facilities in 2022-2025 leaves room to continue developing this. Many battery aspects are included, but the company's main disadvantage is that many of them are currently still in early development stages.

Strengths (+)	**Weaknesses (-)**
Ambitious low-emission battery cars (EQ) in latest models with emission reduction potential from battery production	Many strategies still need to be developed, so which might the challenge the company's ambitious 2039 net-zero target
Strong interaction in reducing emissions from material suppliers and mineral sourcing	Limited level of detail on new battery technologies and planned research and development
High transparency on CO_2 performance and emission reduction data	Few details on vehicle composition and differences PHEV/BEV
Provides information on future battery investments and collaborations	

Acknowledgements

In this page I would like to mention the many people that have been involved in this thesis and the larger research project that it was part of. I would like to thank my supervisors at Utrecht University and NewClimate Institute, who managed to optimally combine their expertise into every round of thesis feedback. Without the data sources and publications they had made available to me, this research would not have been possible. Specifically your helpful and quick replies to my questions and the flexibility you showed after I had to postpone or adjust my work helped me to deliver this final version.

To Robert and Birka, I appreciate your early input during the preparation and proposal phase, when my mind was still filled with doubts and different research possibilities. You encouraged me to start this assignment on a sector that I was unfamiliar with and helped me shape a suitable research objective for all the months that followed.

To Takeshi, thank you for arranging a visit to the NewClimate Institute office during a period where Covid-19 had already complicated so many plans. To all of Takeshi's colleagues in Cologne, I thank you for allowing me to temporarily work in your office and welcoming me the way you did.

To Mark, I thank you for all your practical tips during our weekly meetings and the opportunity of building upon your previous work on emission reductions in the car industry. I am looking forward to the possibility of my findings being used again in your future publications.

Finally, I was able to participate in multiple online and offline meetings, discussions and collaborations about non-state climate action research. It was an honour to meet many non-state climate action experts who also showed interest in my work as a Master student. I am grateful for all of the knowledge that I gained just by being part of this research project.