Conceptualizing and measuring the firm-level transition risk in the auto sector

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Acknowledgment

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Conflict of interest declaration

I conducted this research with Robeco Asset Management B.V. I was situated within the Sustainable Investing Centre and Sustainable Investing Team as part of the thesis requirement. I declare no conflict of interest.

Summary

Problem introduction

The wicked problem of climate change is challenging institutional investors to examine current investment decision-making frameworks. In addition, institutional investors should better consider business transition risks, as the global economic priority trends towards a lower carbon emissions pathway. This shift in priority creates pathways for cleaner policy and technology levers, thus incentivizing businesses to transition. Today, businesses can transition by reducing operations and product emissions footprint or paying more carbon taxes. The failure for businesses to transition risks a decline in corporate valuation, capital liquidity, and lowered business income. Undoubtedly, this shift presents a secondary risk to investors, as the transition risks impact the company valuation and financial return. Therefore, as investment stewards who manage our savings, institutional investors should carefully assess transition risks to inform investment decision-making better.

However, institutional investors have little knowledge and exposure to climate-related technological and policy risks. In recent years, the Environmental, Social, and Governance (ESG) assessment method has dominated the field to assess portfolio transition risks. The ESG assessment method is advantageous as it provides investors with an empirical approach to assessing portfolio-level transition risks. However, the method is inadequate as it relies on third-party mixed approaches to evaluate transition risk based on corporate emissions and environmental data. As a result, the ESG assessment method outcomes are disputed and remain inconclusive to measure firm-level transition risk.

Moreover, the risk output using ESG assessments subjective and qualitative, which is incompatible with a quantitatively driven, financial model-based investment decision-making process. In other words, the current practices provide little to non-existent financial model integration potential. To the best of my knowledge, firm-level transition risk is not well studied, with no established methodology to assess firm-level transition risks, and naturally without any applications in any sectors. Put concretely, the scientific gap is a lack of a firm-level quantitative transition risk assessment framework useful for an investment decision-making process.

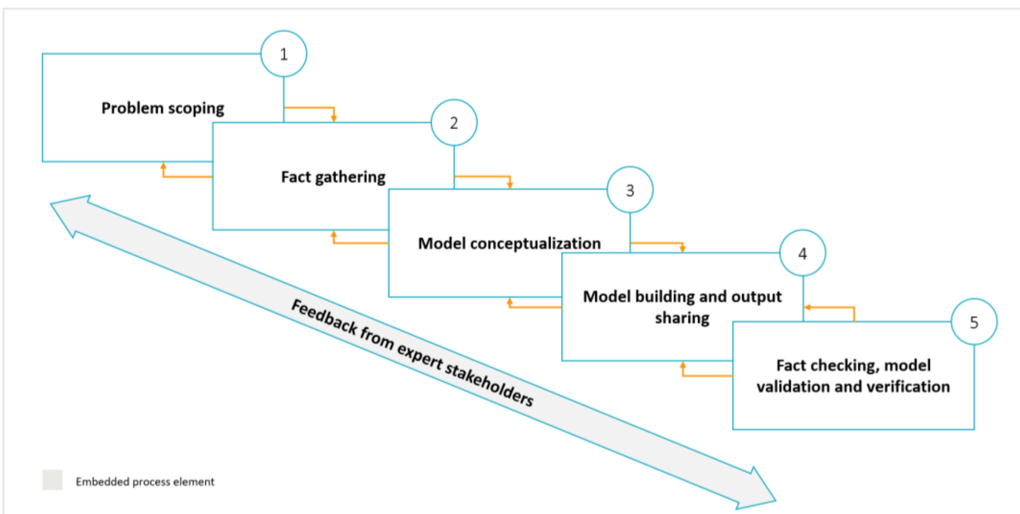
Research objective and methodology

This research aims to assess the novel output integration potential of a firm techno-economic model in an investment decision arena with the aid of a participatory modeling (PM) process. In doing so, the research answers the main research question of: "How can institutional investors study transition risk in the forms of capital requirement and regulatory fines in the auto sector?". First, an extensive literature review helped formulate the main research question.

Next, I conducted a five-step (iterative) participatory modeling process: problem scoping, fact-gathering, conceptualization, modeling, and verification and validation to compute transition risk (see Figure 1). The model operationalizes firm-level transition risk by assessing cash flow at risk through a forward-looking spreadsheet model. The model framework has an auto sector focus because the auto manufacturers have a clear transition capital commitment and a well-established policy framework in the European Union (EU) for transition risk assessment. Hence, the results have higher integration readiness into the investment decision-making process. A use case to test the model is Volkswagen AG, the biggest passenger car original equipment manufacturer (OEM) in the EU.

The participatory modeling setup involves 11 diverse and multidisciplinary expert stakeholders. The model usefulness is measured as a function of the model output integration potential. Finally, The usefulness measurement is done qualitatively through semi-structured interviews with the involved expert stakeholders at the end of the participatory modeling process.

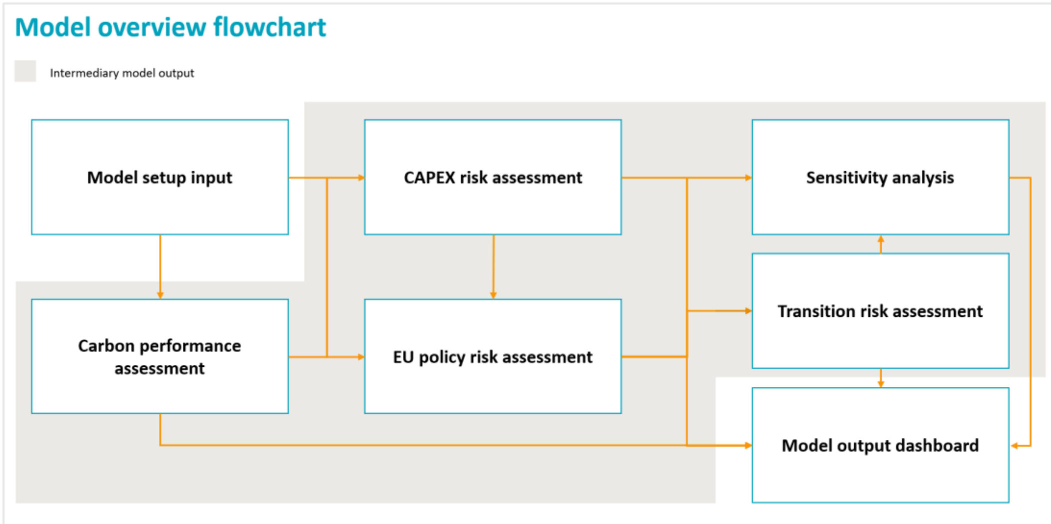
Figure 1: The participatory modeling process used in the research with expert stakeholders in Robeco B.V.



Results and findings

A spreadsheet techno-economic model is designed to assess passenger car auto manufacturers' transition capital and policy risks (see Figure 2). Key input data are the passenger car auto manufacturers' emissions target in the EU and globally, their capital expenditure commitment, the company growth rate, and the EU policy framework measurements. Also prepared is documentation on model setup and dynamics. Workshops were arranged with key stakeholders from various teams to facilitate communication in the modeling process. Semi-structured interviews were conducted with key stakeholders to conclude the participatory modeling process upon model delivery. Additionally, I construct a sensitivity analysis to assess the model's robustness. Finally, I analyze the model output using the stakeholders' input on model usefulness to close.

Figure 2: Model flowchart showing the high-level model setup, with its intermediary model and output components



The model built provides the stakeholders with (i) a carbon performance score to measure OEMs' climate strategy ambitiousness, (ii) a firm-level transition capital risk assessment, and (iii) measurement of potential emissions policy risks subjected by OEMs in the European Union (iv) a sensitivity analysis setup to explore dynamics of auto manufacturers' climate strategy and to build users' confidence level. The results show that the OEM could be bound by policy risk when assessing the relationship between policy and capital risks in the EU. In addition, the cash impact assessed could present volatility to the OEM's cash flow. Moreover, opportunity costs exist, such as capital investment savings and reputational costs, influencing how firm actors craft their corporate climate strategy.

Next, the qualitative feedback gathered from the expert stakeholders agreed that the model is novel, useful, and practical to assess transition risk in the auto sector. Moreover, the model sufficiently scopes the financially material events that could impact an OEMs' transition performance. Finally, the expert stakeholders agreed that this model provides an alternative to the current ESG assessment method and a tangible risk input from a techno-economic model with a physical risk basis.

Conclusion, research limitation, and future research recommendation

This research concludes that based on expert stakeholders' opinions, the techno-economic model developed is a useful boundary object to (i) novelly integrate climate risk research into firm-level investment valuation process, (ii) improve alignment between key stakeholders to assess climate risk in the investment decision-making process and, (iii) provide a grounded basis for institutional investors to perform stewardship responsibilities through engagement. Furthermore, when considering broader societal implications, I reflect that policymakers and auto-manufacturers could use this model to assess transition risk and serve as a communication tool to deliberate on policy designs. The research limitations gathered from the research group concern the standalone use case in a specific sector, data gathering approach, model scalability, and potential biases. These limitations found shall serve as the recommendations for future research in the field.

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1 Introduction

Climate change is an existential threat to humanity that is mainly anthropogenic (IPCC, 2021), underpinned by historically polluting, capitalistic endeavors (Baer, 2012; Vaclav Smil, 2018; Wright & Nyberg, 2015). In the COP26, the world witnessed outpouring support from stakeholders of all aisles, hosting prominent business and public leaders and activists. The congregation signals a change in tone from many unconventional stakeholders since Paris- nation leaders, large public corporations, multi-trillion institutional investors alike (Edgecliffe-Johnson & Mundy, 2021). Within this arena, actors tabled agendas, discussed complications, made deals, reached resolutions, and unleashed all things climate. As the pressure for climate imperatives mounts, so will the need for key stakeholders to act.

Institutional investors are classically responsible for generating financial returns for their clients as investment fiduciary under the tenets of investment stewardship (Novick et al., 2018). Institutional investors are well-positioned to effect strategic agendas in public corporations through engagements (Brav et al., 2015, 2018; McNulty & Nordberg, 2016), and today that includes climate change (Christie, 2021; Krueger et al., 2020; Mercereau et al., 2020). Coalitions such as the United Nations for Principle of Responsible Investment (UNPRI) drive shared agendas for institutional investors (UNPRI, 2015), with their signatories count almost doubling from 2018-2021 (see Figure 3). In the COP26, a staggering $130 trillion in asset under management joint alliance formed between prominent institutional investors made news for committing to be "Paris-Aligned" (GFANZ, 2021). Although asset under management does not translate to a direct increment in the ~$40 trillion required for a 1.5 °C pathway (Yeo, 2019), it points the public corporations under management towards a path with climate in mind.

The number of corporations committing to reduce their emissions footprint reflects this through the Science Based Target Initiative (SBTI, 2021). Since its inception in 2016, the number of corporate signatories has grown exponentially, with almost 2200 companies involved and half of them having 1.5°C reduction pathways. In parallel, increasing weights given to stakeholder-based economy has fueled the popularization of doing businesses responsibly (Eccles et al., 2014; Khan et al., 2016), with the idea that doing good[1] equates to maintaining the social license to operate (Gehman et al., 2017). Supporting this idea is the surge in corporate information disclosed in the forms of environmental, social, and governance (ESG)

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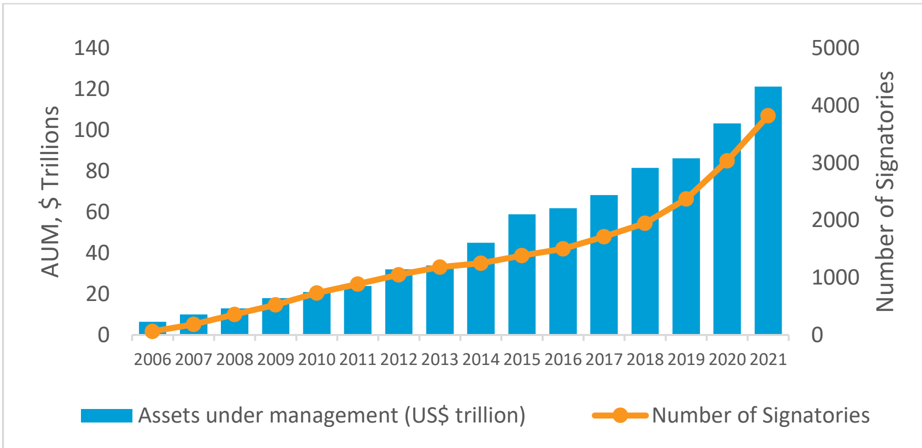
[1] BlackRock CEO Larry Fink, who represents the largest asset manager in the world with >$9.5 trillion in AUM (November 2021), published a client letter in 2020 announcing that businesses do well by doing good, further cementing the popularization of ESG investing (BlackRock, 2020).

issues (Boffo & Patalano, 2020). As a result, institutional investors attempt to integrate ESG factors in climate investing strategies (Bruno et al., 2021).

Figure 3: Aggregated Asset Under Management (AUM) signatories with the UNPRI



However, the conflation of ESG factors in climate investing has yet to prove effective in providing strong financial returns and driving down emissions. The belief that factoring in for more socially responsible companies could provide superior return fuels the popularization of ESG investing. A seminal paper published in 2015 titled *"ESG and financial performance: aggregated evidence from more than 2000 empirical studies"* by Friede et al. claims a positive correlation between companies with high ESG scores and stable Corporate Financial Performance (CFP) through a second-order meta-analysis. This study is significant as many investors took it to justify how ESG performance leads to good CFP, with follow-up studies showing similar conception (Whelan et al., 2018), which led to an influx of investment into the ESG investing space (Tett & Edgecliffe-Johnson, 2021). However, the premise upon which ESG metrics are measured is flawed (Boffo & Patalano, 2020; Bruno et al., 2021; Demers et al., 2021). Indeed, there is a lack of consistency in ESG assessment metrics, with studies finding divergence in the performance of ESG metrics against company returns (Berg et al., 2019; Serafeim, 2021), presenting a need to explore alternatives.

"Although ESG investing performance is disputed, assessing climate risks remain an important issue for institutional investors."

In addition, droves of corporations are committing to ambitious climate targets to answer the call to combat rising temperature, a phenomenon referred to as "decarbonization" or "transition". (Papadis & Tsatsaronis, 2020). Amongst the leading sector in transition activities is the passenger car manufacturing sector. For passenger car automotive original equipment manufacturers (OEMs) - maturing electric vehicle technology, regulation certainty, and rising consumer demand has compelled them to develop climate strategy and commit transition capital expenditure (CAPEX) as the centerpiece in the environmental pillar (the E in ESG).

First, plummeting battery costs in the last few years helped to improve production feasibility for electric vehicles (Bubeck et al., 2016; Cox et al., 2020; IEA, 2020b; König et al., 2021), with plausible cost parity achievable in 2030 (Berckmans et al., 2017; König et al., 2021). Second, regulatory certainty helps to assuage OEMs for a rapid transition. Globally, electric mobility features national policies to decarbonize, with subsidies and tax incentives given to promote electric car sales and to encourage investments in charging infrastructures (Alarfaj et al., 2020; Galvin, 2021; Meadowcroft, 2016; Pianta et al., 2021; Zhou & Kuosmanen, 2020). Key passenger car markets such as India, China, the USA, and the EU are signatories to EV30@30, a campaign to promote sales of electric vehicles by 2030 (IEA, 2021). OEMs face fines in the EU for exceeding fleet emissions at 95 €/ gCO_2, with a proposal to further tighten the limits (European Commission, 2021; IEA, 2021; Tietge, 2018). Third, a growing consumer appetite for low emissions products cements the business case for OEMs to transition (Jochem et al., 2018).

The commitment OEMs made towards a greener future is cheered by all aisles, but measuring the transition risk will challenge investors, given the uncertainty that lies ahead. First, there is a financial risk given the CAPEX assumptions from the OEMs, and notwithstanding reputational risks should they fail. Second, a shift away from ESG ratings requires capacity and domain knowledge building in climate science for institutional investors. Third, within the field of investment management, the framework to assess climate risk tangibly in the passenger car sector has yet to exist. Fourth, even if the assessment framework exists, there is no guarantee of integration possibility, as with ESG. Finally, feeding into this transition risk is also the potential regulation tightening as climate change moves up in the policy agenda.

The scientific gap is a lack of a grounded transition risk assessment framework in the auto sector. In answering the scientific gap, a three-step process follows. First, I conduct an extensive literature review on the problem space that analyzes the current scientific gap to propose the research question. Second, I propose a novel, bottom-up techno-economic transition risk assessment model on the capital expenditure required for an OEM to reach their climate commitment, tested against key drivers. Third, I explore the model integration potential in the conventional investment decision-making process through participation modeling by including experts with domain knowledge in the auto sector, climate science, and investment risk research. In short, the thesis hopes to show that the transition risk assessment model is a valuable addition to the conventional investment decision-making process. This endeavor is apt for our times as climate science becomes mainstream in decision-making, whether in the public or private domain.

1.1 Report structure

The thesis starts with a literature review and main research question formulation. Then, I outline the methods for the techno-economic assessment model and the participatory modeling process. Next, I present the model results and findings. In the last chapter, I close with concluding remarks, a societal reflection, research limitations, and recommend future research.

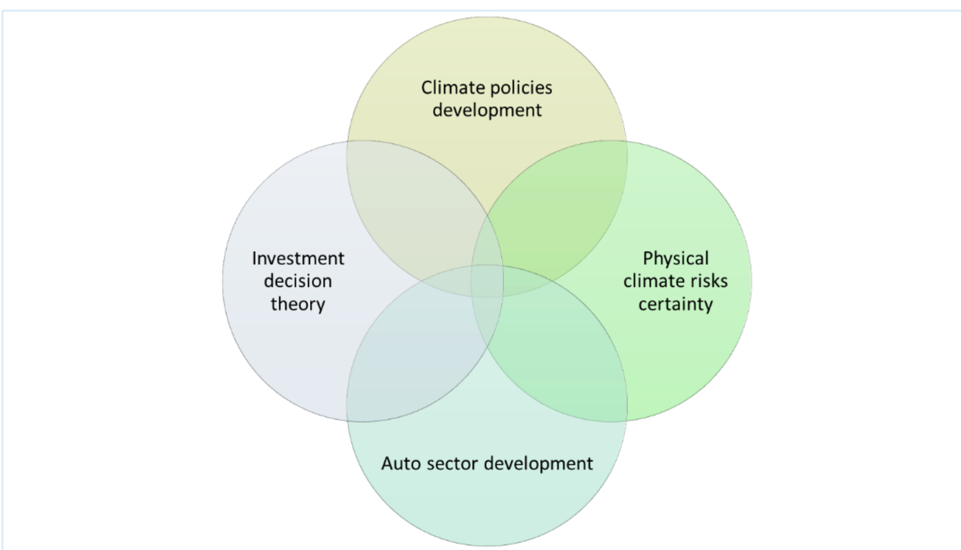
2 Literature review: Theory, knowledge gap, and problem conceptualization

This chapter examines the knowledge gap present in assessing transition risk in the auto sector. First, the review approach is explained to ensure review replicability and integrity. Then, the research introduces and reviews the concept of risk, climate path dependency, *and investment decision theory*. The aim of introducing these concepts is first to understand these individual fields, then explore the theoretical nexus between them, and finally rationalize how they lead to the scientific gap in this research. Finally, the main research question is formulated, supported by the sub-research questions.

Figure 4 is a Venn diagram depicting the theoretical framework from the literature review conducted, where the center represents the knowledge gap of a transition risk assessment. The critical concepts studied are investment decision theory, climate policies development, physical climate risks certainty, and auto sector development. The main finding of the review is the lack of a transition risk assessment framework for investors. This chapter answers the first sub-research question:

"What is the state of development in transition risk assessment for institutional investors?" Figure 4

Figure 4: Theoretical framework capturing the knowledge gap present to assess transition risk in the auto sector



2.1 Review approach

The objective of the literature review is to gain an overview of the key development in the areas of interest. Indeed, the literature review process is an iterative process, and a snowballing technique is deployed as the knowledge premises broadened. I first read review papers to understand the latest development in climate investment and shortlisted key topics for further study. Throughout the process, I had resource support from the TU Delft Library for academic material access, Google as a search engine, and corporate access to the Financial Times from Robeco B.V.

My interest in the nexus of responsible businesses and economic growth sparked the thesis literature search. The work of Edmans published in 2021, "Grow the Pie", provided a strong departure point into the world of ESG investing. The book describes the rise to prominence of corporate stakeholders and the role institutional investors play in aligning business purposes with their extended stakeholders (Edmans, 2021). In total, I came across close to 300 articles with relevance to the topics of interest. The keywords used to initiate the search are combinations of words, split into seven main topics:

Table 1: Literature search keywords used by topics

No.	Topic	Keywords used
1.	Risk and uncertainty	"risks"; "uncertainty and risks"; "climate risk"; "Knightian risks"
2.	Climate policy path dependency	"climate policy"; "policy path dependency"; "carbon lock-in"; "decarbonization policies"
3.	Transition risk	"transition risk"; "climate risk"; "physical risk"
4.	Auto-sector transition	"decarbonization auto sector"; "transition auto sector"; "decarbonization technology auto sector"; "auto sector emissions policies"
5.	Investment decision-making	"active ownership"; "rational expectations"; "alpha generation"; "corporate valuations"; " investment decision-making"; "beta discovery"
6.	Climate investing	"ESG investing"; "climate risk assessment"; "climate funds"; "climate investing"
7.	Research methodology	"techno-economic assessment"; "technological decomposition"; "policy risk assessment"

2.2 ESG investing and climate risk assessment

The literature search performed sought to understand the role of investors, such as institutional investors, in setting corporate climate agendas. The hypothesis is that corporate ownership begets the voice to influence (Brav et al., 2008, 2018; McNulty & Nordberg, 2016). In the process, the notion of climate change, active ownership, investment stewardship overlapped with the rise of ESG investing, with the idea that integrating ESG factors into portfolio valuation helps to generate better returns (Black Rock, 2020; Dimson et al., 2012; Eccles et al., 2014; Friede et al., 2015; Krueger et al., 2020; McNulty & Nordberg, 2016).

Given its popularity in the investing field, this research will briefly touch on the latest discussion in the field of ESG investing, of which the works of (Boffo & Patalano, 2020; Krueger et al., 2020; Unhedged, 2021) provided critical reviews and opinions on the divergence of ESG rating providers due to the inconsistency with the measurement approach. However, I find significant flaws in the narrative of ESG factors integration in investment strategies and financial returns. (Berg et al., 2019; Bruno et al., 2021; Cheema-Fox et al., 2019; Demers et al., 2021). Major disagreements exist on ESG investing approaches (Bruno et al., 2021; Tett & Edgecliffe-Johnson, 2021; Unhedged, 2021).

After all, measuring ESG metrics' social and governance aspects can be subjective and hard to quantify. Moreover, the only link found on climate risk assessment and ESG is through a temperature traffic light system, which provides a basic qualitative ranking on the carbon performance of certain corporations. However, it does not provide concrete risk assessment and integration potential into the investment valuation process (Mercereau et al., 2020). Ultimately, I shall partially reject ESG factors as the basis for climate risk assessment, given flawed assumptions supporting the core belief that integrating ESG assessment improves investment returns (generate alpha) and reduces risks (beta reduction). I opine that the ESG approach alone is insufficient for climate risk assessment.

Therefore, the research sought to elucidate the landscape of transition risk assessment for institutional investors by exploring the state of art within transition risk assessment and its potential application in the auto sector. The review from Hong et al., 2020 and van Dijk, n.d. provided the latest open research questions and modeling techniques in climate finance potentially useful for institutional investors and thus setting the grounds for research. The participatory modeling choice is motivated in Chapter 3.1.1, disclosing the modeling approach and participatory modeling process.

2.3 Funding transition: risk, climate path dependency & investing in the future

For the topic of risk, I started with a review by (Aven, 2016). As for climate change, the spotlight is on climate governance and policymaking, and the work of (K. Levin et al., 2012) helped shape my thinking. Finally, on investment decision theory, I sought to understand the key drivers affecting investment decisions, and for that, the works of (Christie & Christie, n.d.; Giglio et al., 2020; Hong et al., 2020; Nordhaus, 1977; van Dijk, 2021) were helpful.

With the review, I draw on the key concepts introduced and explore why institutional investors pay great attention to risks and manage risks against the larger backdrop of climate uncertainties before 2016. In short, I found that with increasing climate policy certainty, so does the investor’s confidence in funding climate transition. However, risks still exist within the field, and there is no clear, established way for investors to manage those risks.

2.3.1 Risk

Understanding the subject of risk itself is crucial to grasp its significance in our lives fully. The word “risk” is expressed both colloquially and academically. But risk itself as a subject is broad. The non-technical definition of risk is *“an unwanted event which may or may not occur”*. Despite its perennial existence as a subject broached by various ancient philosophers, it is a relatively young scientific field with formal establishment only since the 1970s; with the standard, accepted technical epistemology of the term "risk" defined as:

"The fact that a decision is made under conditions of known probabilities",

which strictly distinguishes between *"decision under risk"* and *"decision under uncertainty"* (Rasmussen, 1974; Rechard, 1999; Sven Ove, 2018). Nonetheless, there exist many other subfields within risk, and for further definitions, please refer to (Aven, 2016; Hansson, 2013; Sven Ove, 2018).

In practice, the concept of risk is applied in policymaking, in business strategy, and of course in trivial, daily decision-making "(Sven Ove, 2018)". With strengthened confidence in climate science and thus climate risk, decision-makers from all aisles are confronted with deciding how to protect their interests and goals best. By ordinary standards[2], the theoretical approach to risk relies on maximizing expected utility, which is an extension of utilitarianism (J. Levin, 2006; Sven Ove, 2018). In practice, a simplistic utility maximization approach applies in policy decisions, such as using a cost-benefit analysis, with sufficient accuracy and usefulness indicated through policy outcomes (Posner & Adler, 1999).

2.3.2 Risk and uncertainty

Uncertainty as a subject is relatively diverse, with various typologies, definitions, and subfields of study. For example, in 2013, Walker et al. defined uncertainty as limited knowledge about the future, past or current events. Typically, uncertainty can be represented stochastically in the forms of probability. But the stochastic representation can be heavily subjected to the subjectivity of those involved. Sometimes, actors cannot agree on uncertainty itself, limiting the extent of decision-making outcomes.

In economic life, a risk exists when one sets out to take on uncertainty or when uncertainty is reduced into risk, which denotes the calculable and controllable (Emmett, 2020; Knight, 1921; Magnani & Zucchella, 2018). As discussed under decision theory, using prescribed values expressed in utilities to assess risk can contribute to decision-making.

Next, I invite the readers to understand how path dependency reduces uncertainty into risk factors for investors and thus sets the stage for investors' role in climate transition investment.

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[2] Other ways of approaching decision making includes prospect theory (Kahneman & Tversky, 1967), but is criticized for being ergodic (all outcome probabilities do not have influence on another) and deviates from other expected utility theory. However in 1982, Quiggin proposed a theory of anticipated utility which introduces rank dependent probabilities (non-ergodicity) into the expected utility theorem, which is shown empirically more adequate to determine expected utilities in real life, often sequence dependent conditions (Harrison & Ross, 2017).

2.3.3 That night in Paris and the birth of climate path-dependency

[If Frost had been more mathematically inclined, rather than writing, "Yet knowing how way leads on to way, I doubted if I should ever come back," he may have written, "Yet knowing the paths were not ergodic, I knew that I should never come back.", (Page, 2006)]

The Paris Climate Agreement in the Paris Climate Conference (COP21) serves as the mother of all things climate in this century. In this historic feat, where 195 United Nations Framework Convention on Climate Change (UNFCCC) participating member states adopted the Paris Climate Agreement by consensus, paved the way for future dialogues to place weights on addressing this existential threat. But before even attempting to solve the problem, we must first understand it. To do so, I explore the complexity climate change brings, the key developments that have happened since, and how policy developments accelerated participation from private actors.

2.3.3.1 *Climate change is a super wicked threat*

Climate change is a class above contemporary policy challenges and is a "super wicked" problem- occurring in open, non-linear systems (K. Levin et al., 2012). Piling on to the definition of the ten traits of wickedness[3] as described by Rittel & Webber in 1973, the climate change super wicked problem is magnified by four more characteristics: (i) time is running out (to address it); (ii) there lacks central authority to address the issue; (iii) climate contributors could also be climate solvers; (iv), and actors may choose irrational moves with hyperbolic discounting[4] (Jaques, 2008; K. Levin et al., 2012). Recognizing this is paramount, as there is no one right way to address the issue. And next, we turn to what incremental change state actors have proposed since Paris.

2.3.3.2 *Sticky momentum for actions*

Akin to inertia in physics, policy path dependency sustains and supports the trajectory of a social system. Markedly, the COP21 gave way to the emergence of a self-reinforcing, increasing rate of return in climate policy path dependency (K. Levin et al., 2012; Mima & Strolyarova, 2018). Since then, the climate policy landscape underwent a torrent of change, permeating various decision arenas, with

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[3] In their seminal work "Dilemmas in General Theory of Planning", Rittel and Webber in 1973 laid down the ten characteristics of a wicked problem that is used today to describe complex, interconnected, and sticky problems.

[4] A clear example of hyperbolic discounting is the refusal of policymakers and corporations alike to adopt carbon pricing, which shows immediate effect on emissions reduction. Instead, they are more interested in relying on a more costly technological and speculations, which may or may not provide desired results in the future. In doing so, they would have to apply a favorable discount factor on the efficacy of the future technologies. (Fried et al., 2021; K. Levin et al., 2012; Meckling et al., 2017)

state actors and private conglomerates revising their attitudes on the climate imperative (see *Table 2*.

Table 2: Nationally Determined Contribution target overview by key polluting state actors, collectively making up 45% of global emissions

Country	CO_2e emissions in 2018, tonnes [%]	Climate statement	Year
China	11.7 [23.92%]	"China aims to have CO2 emissions peak before 2030 and achieve carbon neutrality before 2060; to lower CO2 emissions per unit of GDP by over 65% from the 2005 level, to increase the share of non-fossil fuels in primary energy consumption to around 25%, to increase the forest stock volume by 6 billion cubic meters from the 2005 level, and to bring its total installed capacity of wind and solar power to over 1.2 billion kilowatts by 2030."	2021
US	5.8 [11.84%]	"United States commits to reduce net GHG emissions by 50-52% by 2030 compared to 2005 levels."	2021
EU-27	3.3 [6.84 %]	"The EU and its Member States, acting jointly, are committed to a binding target of a net domestic reduction of at least 55% in greenhouse gas emissions by 2030 compared to 1990."	2020
India	3.3 [6.84%]	To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from the 2005 level.	2016

The four biggest emitters in the world - China, the USA, EU-27, and India, collectively emit 50% CO_2e in the world annually, have all injected crucial momentum into a desperate climate policymaking arena with clear climate targets (Pianta et al., 2021; Walenta, 2020; Wimbadi & Djalante, 2020). Developed states, such as the European Union and the U.S., have committed to net-zero targets by 2050. The European Parliament has gone as far as to declare a Climate Emergency, with aggressive adjustments proposed to climate policy instruments and targets to fully align with a 1.5 °C pathway (European Parliament, 2019). These developments have undoubtedly provided much-needed clarity to non-state actors, who contribute to path dependency acceleration through voices, innovations, and coalitions.

2.3.3.3 *Growing actions on the back of Paris*

In the GOP26 held in Glasgow, $130 Trillion was the number paired with major news headlines. This number represents the aggregated asset under management committed towards a net-zero 2050 pathway. The number itself is flawed[5], but it nonetheless carries a significant confidence signal to other actors participating in the arena. On the back of Paris, we saw the culmination of ideas and actions from different parties- academics, corporate activists, and joint alliances

[5] The figure faces criticism from parties because it is duplicative due to asset owner and institutional investors both committing their managed capital towards the coalition.

governing bodies. Table 2 provides selected initiatives and organizations with active applications in the asset management field.

Table 3: Typology of non-state actors' response in concomitant to state-led climate policy actions

Category	Names	Objectives	Participation/ stakeholder responses
Academia / Science-based initiatives	Science-Based Target Initiative	1. Provides a science-based methodology to guide companies on transition target setting 2. Provides both sectoral decarbonization approach (SDA) or absolute contraction approach 3. Tracks firm-level activity through absolute and intensity-based carbon metrics	• >2,000 participating companies • ~50% with net-zero 2050 (1.5°C) targets
Academia / Science-based initiatives	Transition Pathway Initiative	1. Tracks firm-level activity through absolute and intensity-based carbon metrics 2. Assesses corporate climate targets for forward-looking projections	• Close to 500 participating companies
Climate financial risks/ data portals	CDP (formerly known as Carbon Disclosure Project). GHG Protocol	1. Collects primary CO_2 emissions and climate governance data from corporations 2. Serves as a database for interested stakeholders incorporate carbon emissions and governance 3. Guide carbon emissions accounting and auditing	• >13,000 companies reporting data on climate change, water security, and forests
Non-profit/ joint alliances	ClimateAction100+ (CA100+)	1. Monitors and engages corporations who are high in carbon intensity and emissions 2. Serves as a platform for climate ambitions and target declaration for corporations	• 167 highly emitting companies on engagement list focusing on climate governance and transition risks • 400 investors participating in joint engagement
Non-profit/ joint alliances	Climate Action Tracker	1. Tracks state and corporate level climate targets and policies against climate pathways 2. Provides strong visualization of climate action progress for interested stakeholders	• Tracks 39 countries covering 85% of global emissions
Investor coalition	United Nations Principles for Responsible Investment	1. Promotes the adoption of ESG in investing 2. Recommends climate risk assessment from a fundamental approach	• Close to 4000 investors are signatories to the coalition
Corporation coalition	United Nations Global Compact	1. Promotes sustainability and responsible businesses practices, i.e., human rights, labor, environment, and anti-corruption	• 7,000 corporate signatories in 135 countries

Table 3Table 3 effectively illustrates how various non-state actors are coming together to advance climate actions through capital commitment, transition strategy guidance, reporting and data governance, and advocacy efforts. Assuredly, the coverage of these initiatives is high and involves major emitting parties. Therein, it is appropriate to suggest that we see the sizeable momentum and buy-ins from various parties who inadvertently promote a sense of certainty for the actors in the market, given the private actions and policy support. Next, attention is given to investors to understand why and how they are fighting climate change.

2.4 Investment decision theory and climate risk

Informational asymmetry is manifested in the forms of uncertainty in a capitalistic market. For long, investors have rejected the practical basis of the efficient market hypothesis (EMH), given the natural state of informational asymmetry in society (Malkiel, 1989). Without asymmetry, investors would not exist to seek returns (or alpha) (Anson, 2012; Malkiel, 1989).

Uncertainty in climate change adds to the state of asymmetry in the market, prompting a need to insert climate risks into the investment decision-making process (Basaglia et al., 2020; Fried et al., 2021; Gavriilidis, 2021; UNPRI, 2015). To do so, investors should consider physical and transition risks (Bachner et al., 2020; Basaglia et al., 2020; Incropera, 2015; International Energy Agency, 2007; Maier et al., 2016). Fortunately, in recent years, the seismic shift in climate agenda priority for critical decision-makers has reduced uncertainty into probable policy risks (Krueger et al., 2020). This clarity is essential for investors as they can now meaningfully act upon the information to assess climate underperformers.

2.4.1 Investing under uncertainty

In 1961, Ellsberg cleverly designed a choice experiment targeting the subjectivity in probability allocation in daily choices for ordinary folks to understand how we make choices in life. Additionally, the academic purpose of the experiment is to challenge the von Neumann-Morgenstern theory of risk treatment that assumes objective probability, which Savage in 1950 had built on the risk model.

Ellsberg's Experiment (J. Levin, 2006)**:** An urn contains 300 balls; 100 are red, and 200 are some mix of white and blue. We are going to draw a ball at random.

Scenario 1. You will receive $100 if you correctly guess the ball's color. Would you rather guess red or white?

Scenario 2. You will receive $100 if you correctly guess a color different than that of the ball. Would you rather guess red or white?

From the experiment, Ellsberg found that participants would choose red in both scenarios- although the chances for white in both outcomes are arbitrary, which could either be larger, equal to, or lesser than red. In any case, for choice makers who can discern this arbitrary property, they should not have been able to support their choices meaningfully based on non-speculative approaches. Next, I put into context how this experiment depicts the problem of climate change, climate policy, and investors' risk aversion.

2.4.2 Capitalizing on climate risk

"Transition risk the financial risks which could result from the process of adjustment towards a lower-carbon economy. "

– Mark Carney, former Governor Bank of England, 2015

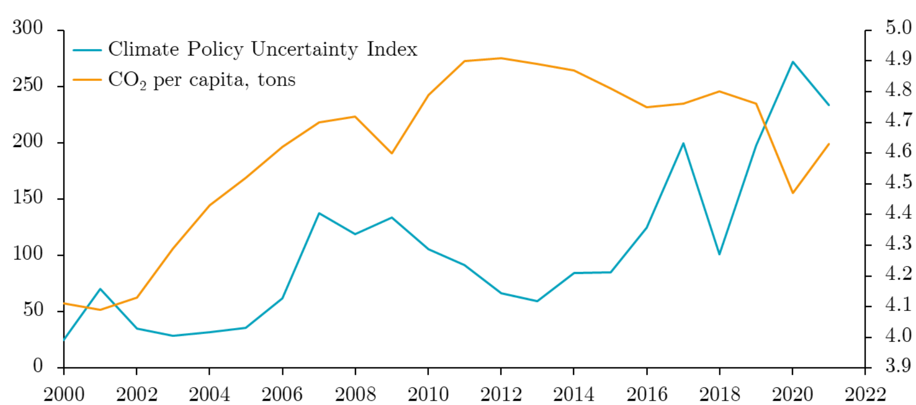
Investing means sacrificing the present for future benefit (Hirshleifer, 1965), where uncertainties thrive. Climate change adds to the puzzle by introducing these unknowns, given the way we should evolve in our modus operandi towards a greener lifestyle. Drawing inspiration from Genesis 1:1- *in the beginning*, there was only climate change, and then there were climate policies. Going back to Ellsberg's experiment:

Suppose that the red ball and its 1/3 probability are assigned to climate change. The mix balls are policy unknowns represented in unquantifiable, arbitrary probabilities, and the participants are investors. To extend the experiment to reflect the market using scenario 1, the participants will also have to bet with random antes with immediate disqualification if they lose. They can choose to bet or not. Moreover, the rule stipulates that the investors are given extra information on the color mixes after a few rounds.

Naturally, with the uncertainty present, none will place bets on the climate transition, apart from speculations (Foerster, 2014). And such is the case for climate investing in its early years. But policy certainty acts as a confidence booster to help investors assign a subjective probability of successes (and failures). It is akin to introducing transparent glass panes to the box, and now participants can count the color mixes and estimate them; the glass panes helps reduce climate uncertainty to risks (J. Levin, 2006; van Dijk, 2021).

In 2021, Gavriilidis introduced a climate uncertainty measurement that deploys text analysis in major US news outlets on words related to climate policies to measure climate policy uncertainty. *Figure 5* shows that the climate policy uncertainty (CPU) score increases against emissions as investors invest more in environmentally friendly technologies. This observation is attributable to the analogy above, where climate policy disclosure and increased reporting can lead to transparency in information dissemination.

Figure 5: Climate Policy Uncertainty Index that measures news reporting concerning major climate policies (Gavriilidis, 2021; The Global Carbon Project, 2021)



In slight technical terms, investment beneficial to climate change is now quantifiable. As a result, investors can now build confidence based on available market information and increase investments activities (Bernanke, 1983).

2.5 Conceptualizing climate change, corporate climate targets, policy risks, and investments

This section formalizes the key concepts introduced connecting climate science, corporate transition, climate policies, and climate investments. This conceptualization establishes the core relationships between critical drivers studied, the transition risk, and the transition risk in the auto sector.

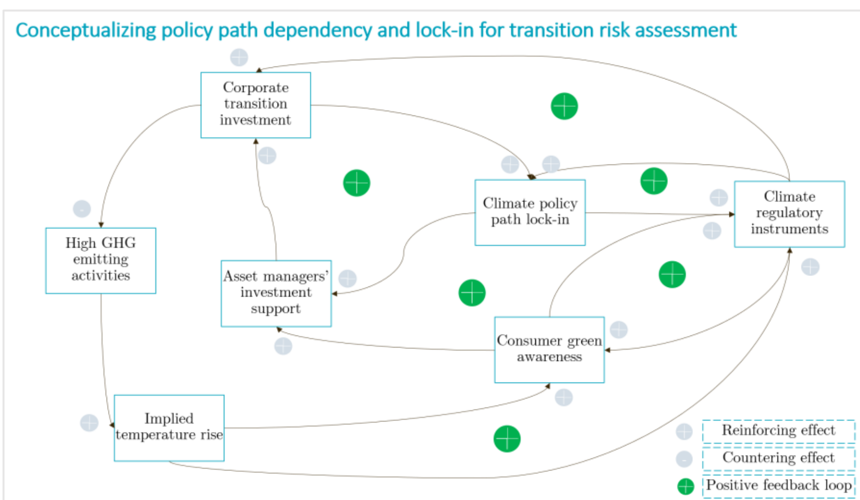
2.5.1 Conceptualizing transition risk for investors

The literature review so far provided much understanding into the relationship between climate change, state and non-state actors, and financial risks. Therefore, I define the transition as:

"A systemic multi-actor dependency to address climate risks and opportunities in less carbon-intensive economic activities through the investments in transition technologies and divestitures"

A high-level causal loop diagram (CLD) accompanies the definition and conceptualizes the relationship between various actors, key drivers, and outcomes (*Figure 6*). From the CLD, I observe that multiple positive feedback loops lead to increased climate policy path dependency, corporate climate investments, and ease of introducing more climate regulatory instruments. I also see that increasing climate policy path dependency can accelerate corporate investments in transition. These positively reinforcing feedback loops are essential, as they ultimately contribute to the momentum in transition.

Figure 6: High-level causal loop diagram (CLD) showing the path lock-in positive feedback loops between corporate investment, climate regulatory instruments, and institutional investors' investment support



Note that the causalities here are in loops, but I hypothesize that consumer interest and regulatory support are the catalysts. I assume that climate science is well-established with high confidence. I will further define the "stocks" (blue boxes) in the following points:

Consumer green awareness. Consumer green awareness is supported by increasing citizen awareness of climate change. In response, consumers begin to shift purchasing and consumption behavior. They discern between polluting, unsustainable, and harmful products and low carbon intensity and healthy products. They lobby regulators, politicians & policymakers to introduce climate regulatory instruments. They also voice out against investing their savings in highly carbon-intensive portfolios. Increasingly stringent climate regulations could further raise their interest in introducing other climate-friendly instruments (Lee et al., 2015).

Climate regulatory instruments. Climate regulatory instruments are interventions policymakers use to incentivize or penalize carbon emissions. Some examples are the carbon tax, EU Emissions Trading System (ETS), European Border Tax, carbon intensity limits, and the subsidies for various technologies mainly to promote low carbon activities. In the CLD, the climate regulatory instruments affect corporate investment in transition positively by making greener activities cheaper and less risky. Conversely, the instruments introduce financial risks through fines for exceeding carbon limits. Furthermore, as alluded to, consumer demand for greener products and lifestyles also drives regulatory actions.

Climate policy path lock-in. The path lock-in is a conceptual sunk cost invested by public and private actors as they invest more and more in low carbon activities. In that sense, public and private actors will gain confidence in low carbon activities and introduce more climate-friendly regulatory instruments. In some cases, corporate actors might even lobby for climate regulatory instruments to gain an advantage.

Institutional investors' investment support. Investors are by professional requirement motivated to assess risks. However, they rely on external signals to translate them into risk levels. In this case, they would appreciate high climate policy path lock-in (clear policy risks level) and consumer green awareness to build investment theses.

High GHG emitting activities. High greenhouse gas (GHG) emitting activities denote high carbon economic activities as a share of overall economic activities. As companies invest in transition, high GHG emitting activities will reduce as a share of the overall economic activity, thus driving overall intensity lower. The equilibrium of the ratio is when the temperature is at 1.5°C. A higher than equilibrium GHG emitting activities ratio indicates a higher implied temperature rise, given the need to taper carbon emissions towards a net-zero pathway.

Implied temperature rise. This indicator reflects the overall carbon intensity of the economy. This indicator informs the gap between the GHG intensity level and the 1.5°C climate pathway. An intensity level exceedance from this pathway will continue to drive green awareness in consumers and an increase in climate regulatory instruments.

2.5.2 Knowledge gap: Firm-level transition risks assessment in the auto sector

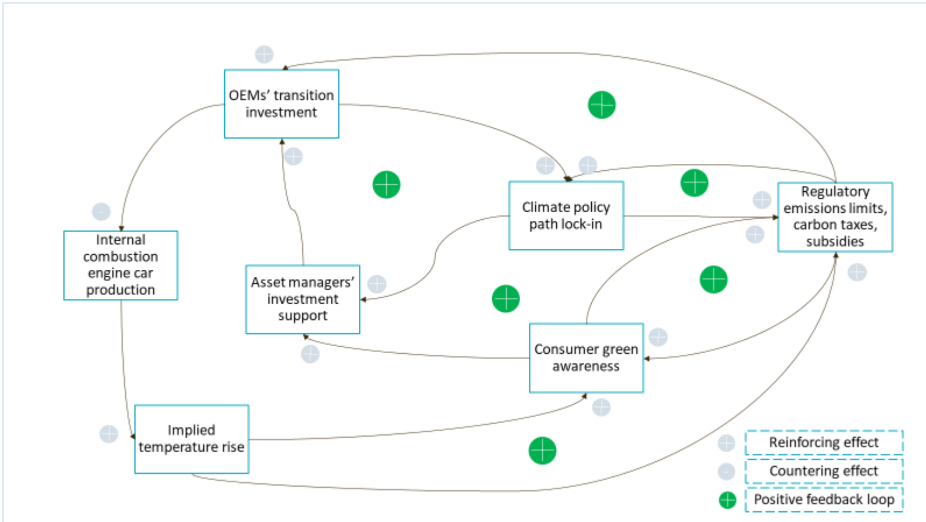
This thesis adopts a firm-level approach as, to the best of my knowledge, firm-level transition risk is not well studied, with no established methodology to assess firm-level transition risks, and naturally without any applications in any sectors (Dietz et al., 2021; Reid et al., 2021; UNPRI, 2015; van Dijk, 2021).

To conceptualize the transition risk further, Figure 7 shows policy and legal, technological, market, reputational, and possibly other risks within the transition risk category. Therefore, the research boundary combines the UNPRI transition risk framework, the established conceptual knowledge of the auto sector transition, and the understanding of the financial risks.

Figure 7: Climate-related risks and opportunities (PRI, 2018)

Likewise, the conceptualization in *Figure 6* applies to the auto sector, where various positive feedbacks push the passenger car manufacturers (OEMs) into transitioning (see Figure 8). While this cannot be said for some hard-to-abate sectors, i.e., cement, chemicals, aviation, et cetera. This observation is astute in the auto sector- since the technological, political, and demand levels are high and ripe for a sectorial pivot. For example, in 2021, many OEMs set climate targets and committed large sums towards electrification.

Figure 8: Conceptualizing policy path dependency and lock-in for the transition risk assessment in the auto sector



There are nascent works of literature assessing macroeconomic and portfolio level impact of climate physical, transition, and policy risk suggests that the climate risk factors are impactful on investment performance (Bachner et al., 2020; Fried et al., 2021; Hong et al., 2020; Monasterolo et al., 2018; Reid et al., 2021). Moreover, although gaining popularity, the current practice of ESG risk integration is not proven and is subjected to much debate on its measurement standards, methodology, and integration approaches (Boffo & Patalano, 2020; Bruno et al., 2021; Johnson, 2021; Li & Polychronopoulos, 2020; Stackpole, 2021).

As a result, this thesis excludes macro-level impact and physical risk assessments, as well-established methodologies and frameworks are assessing these impacts in different regions (Ciscar et al., 2011; Giglio et al., 2020; Magnan et al., 2021; Semieniuk et al., 2021; Welsby et al., 2021; Xie et al., 2015). In short, the research establishes its boundary around firm-level transition risks, relying on individual climate target and commitment data as the departure point.

2.6 Review concluding remarks

The literature review explored the intersections between risks and uncertainty, climate policy developments and path dependency, and investment decision theory. The review found that risk is a diverse field of study, but when applied in decision-making in an uncertain environment, the risk is expressed in utilities. In addition, climate policies are experiencing incremental support, resulting in a less uncertain environment, thus empowering various stakeholders to undertake climate-related decision-making, including investing in climate initiatives. Nonetheless, not all corporations are ready for the transition since technology, policy maturity, and consumer demand is important.

Insofar, the intersection of the theoretical frameworks revealed a limitation in assessing firm-level transition risk in the auto sector. This limitation prompts new knowledge discovery in the investment field in addition to the popular ESG metric, which is a qualitative method that struggles to reconcile with the traditionally quantitative financial valuation field. Moreover, the auto sector is indeed ready for a transition, with increasing climate targets and commitment set in public but is without a transition risk assessment framework.

The scientific knowledge thus lacks a transition risk assessment framework in the auto sector for institutional investors. Therefore, further research needs to stand firmly on the academic grounds of finance and climate sciences to enhance scientific knowledge.

2.7 Research question formulation

In accepting the challenge to develop new knowledge to assess transition risk for institutional investors, this thesis attempts to address the following research question:

"How can institutional investors study transition risk in the forms of capital requirement and regulatory fines in the auto sector?"

Additionally, four research sub-questions will support answering the main research question.

The first step establishes the key development within the sustainable investing movements by understanding current climate performance measurement methods and defining key transition risks. Therefore, the first research question is:

1. *What is the state of development in transition risk assessment for institutional investors?*

The second step asks the methodologies supporting the transition risk assessment, with the purpose to elucidate the audience with the modeling choice motivation, and introduces background information for participatory modeling:

2. *What are the proposed methods to assess firm-level transition risk based on the climate strategies of car manufacturers in a diverse stakeholder group?*

The third step proposes techniques to target key transition risks, operationalize risk measurement, and propose a model to assess climate targets against relevant transition risk drivers. Therefore, the third research question is:

3. *How to conceptualize, operationalize and assess the transition risk in the auto sector using a techno-economic assessment model?*

The fourth step concerns the model usefulness, investment decision-making integration potential and considers the working context with an expert multi-actor system. Therefore, the fourth research question is:

4. *What is the integration potential of the transition risk assessment tool in the context of a diverse expert stakeholder group?*

3 Research methods

This chapter introduces the research methods used to build a transition risk assessment model. The research combines a mixed quantitative techno-economic assessment (TEA) method with a qualitative participatory modeling process. Additionally, the chapter motivates the suitability of the TEA and participatory modeling methods; the chapter also intends to answer the following sub-research question two:

"What are the proposed methods to assess firm-level transition risk based on the climate strategies of car manufacturers in a diverse stakeholder group?"

3.1 Suitability of techno-economic assessment for transition risk assessment in the passenger car sector

In this section, I introduce the method of a techno-economic assessment (TEA) and motivate its suitability to study transition risk from an institutional investors' perspective. There are three reasons why a TEA is appropriate. First, I mainly observe increases in climate data disclosure in carbon emissions and climate targets on data collection. Moreover, there is an uptick in technological investments needed towards lower emissions pathways in the auto sector. Finally, I also register the emergence of financially material transition risk for OEMs who choose not to invest in the future by shifting towards a greener product portfolio.

3.1.1 Techno-economic assessment method

Techno-economic assessment relies on systems of equations to represent an abstraction of reality from a technological, markets, and policy angle (Ansolabehere, 2004). The methodology is commonly used for large-scale, industrial investment projects (Raj et al., 2016; Schinko et al., 2019; Simmons et al., 2015). Using a techno-economic assessment aims to connect technology to economics, for example, operationalized using capital cost and returns (if applicable). It is a bottom-up approach that requires technical input, i.e., production capacity, efficiency, working rates, et cetera., to achieve technical requirements such as production, transport, or generation. Typically, researchers deploy techno-economic assessment to provide cost assessment following the technical requirement stipulated or provide technical requirements based on the cost provided (Kang et al., 2015; Offer et al., 2011; Raj et al., 2016; Simmons et al., 2015). In addition, techno-economic assessment applies to optimization issues (Berckmans et al., 2017).

3.1.2 Increase in climate commitment data availability

Data (information availability) is essential for decision-making, for, without it, there is no way to justify an action[6]. The Transition Pathway Initiative prescribes

[6] Or without it, the people can only believe in God.

the physical transition pathways by specifying the intensity reductions needed for companies using a sectorial decarbonization approach. Rather importantly, this information serves as the reference point for which companies in various sectors determine their carbon intensity aspirations. Today, many corporations declare their climate targets and have been undertaking transition efforts. This development is especially significant in the passenger auto manufacturing industry. The top 10 car makers, making up close to half the market sales in 2020, have committed to net-zero latest by 2050. In addition, on an annual basis, companies are disclosing how much CO_2 they are emitting and their product fleet carbon intensity.

The carbon intensity is determined using a weighted average intensity, split between the emissions intensity of the cars produced. Therefore, the intensity target data points are helpful for investors, as they allow outsiders such as investors to understand the carbon intensity gap between the current production level and the future intended intensity level, considering the growth trajectory that the company is presenting to investors. With this understanding, investors can then apply a forward-looking view using techno-economic assessment to explore the future carbon intensity and whether the OEMs commit sufficient investments in production capacity to reach their targets.

3.1.3 Financial risk materiality in the passenger car manufacturing sector

For passenger car manufacturers (OEMs), the motivation to transition is on two fronts. First, it is attractive to produce battery electric vehicles (BEVs) thanks to decreasing cost and increasing demand drivers. There are many incentives to promote the purchase and use of passenger cars. For example, owning a BEV is attractive for consumers because of the substantial subsidies provided by the government. At the same time, governments with pro-BEV agendas are also incentivizing investment in charging infrastructures through various initiatives, further driving uptakes. Additionally, the critical cost component- batteries, are facing exponential decline, given the recent diffusivity in battery technology. Not only that, but OEMs also have strategic interests to count on the economy of scale and first-movers advantage to gain a competitive edge against peers.

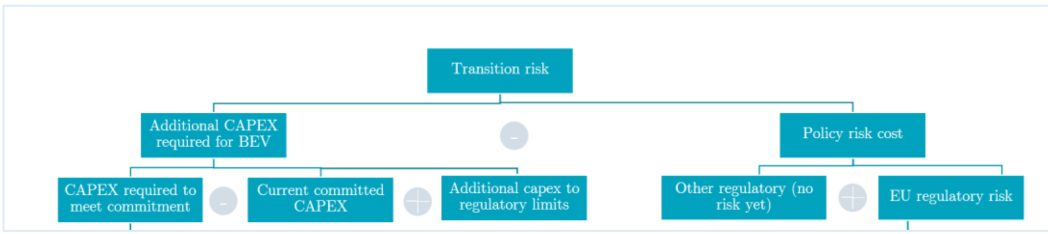
Secondly, punitive regulatory measures are beginning to gather critical mass, especially in Europe, where the Big 3 manufacturers[7] dominate sales. In 2020, Volkswagen about €100 million in fines to the European Commission (EC) for violating the regulatory intensity limit (Reuters, 2021). The EC is also looking to tighten the said regulatory limits, with the EU “Fit for 55” under negotiation. The EU “Fit for 55” aims to align regulatory limits with the EU’s 2030 climate target. The proposal effectively calls for a 55% reduction in carbon emissions compared to 1990 levels, up 17.5% from the current goal of 37.5% reduction (European Commission, 2021a). Looming slightly further for the OEMs is the plan for the EU to

[7] The Big 3 are referring to Volkswagen AG, Daimler AG, and BMW AG.

phase out internal combustion engine (ICE) vehicles by 2035. Indeed, this puts pressure on the OEMs compounded on market competition.

Currently, it is unclear if OEMs are on track to meet these regulatory targets in the future. However, failing to do so could invite financial regulatory penalties in specific regions and impact investor confidence in the company. For that, a firm-level assessment of an OEM's capital expenditure in production capacity could prove useful when measured against future regulatory limits when assessing transition risks. And this thus sets up the highest-level techno-economic model dynamics, as stylized in *Figure 9*.

Figure 9: Highest-level model structure where transition risk conceptualized as the sum of estimated additional CAPEX required and policy risk cost



3.2 Participatory modeling core definitions

For this thesis, I work within Robeco B.V. I invited eleven (11), expert stakeholders/ practitioners from three functions to be part of the modeling process. The practitioners are multidisciplinary with economics, finance, climate sciences, and engineering backgrounds.

Bringing together diverse stakeholders promotes alignment in model construction to test the model's usability, continuity, and integration possibility in the current decision-making process. One established methodology that can do so is participatory modeling (Voinov et al., 2018). The state of development in the participatory modeling approach is scrutinized to determine the best possible approach within the subfields that supplements the chosen modeling approach (van Bruggen et al., 2019).

3.2.1 Participatory modeling with expert stakeholders

The research aims to know if the transition risk output could be integrated into the investment decision-making process, measured as the model usefulness. Furthermore, by involving key stakeholders, the participatory modeling approach helps to enhance conceptualization, improve the model structure, and improve alignment on subjective values. Therefore, involving stakeholders through participatory modeling could be valuable.

The transition has brought the need to consider sustainability in their business operations, including the investment decision process. The sustainable investing team within the asset management firm is responsible for assessing climate risk across sectors. They collaborate with experts from fundamental investments and the active ownership team. The fundamental investments team is responsible for screening financial attractiveness and maximizing alpha. The active ownership team is responsible for portfolio engagement on behalf of the institutional investors to influence corporate climate agendas.

However, the experts from other functions lack climate and transition science knowledge capabilities. At best, they are familiar with the concept of climate risk but lack the in-depth knowledge to combine climate, technological and policy issues into concrete risk assessment methods. The investment team has the expertise in sectorial growth trajectories and can point out financial limitations in companies. The engagement team is skilled in communicating insights from risk assessment frameworks to influence corporate agendas.

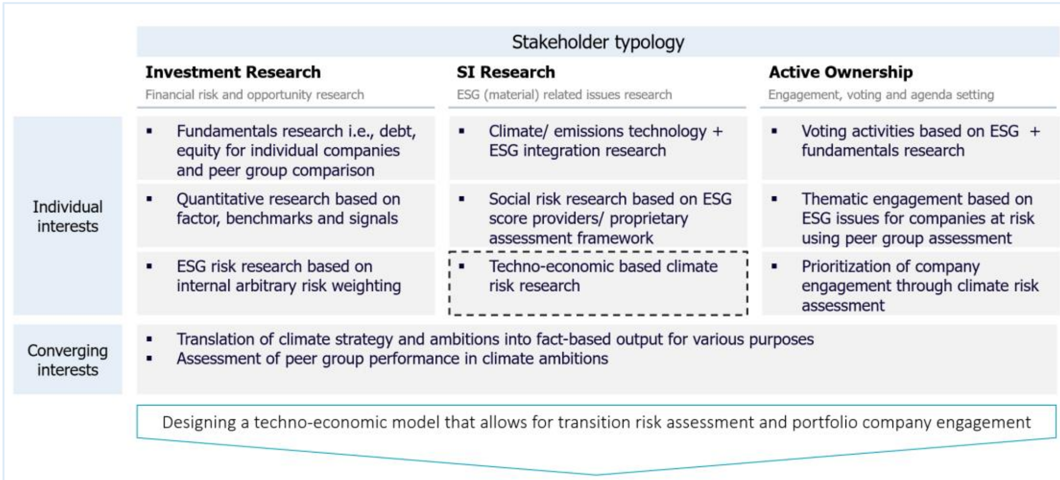
Moreover, most modeling exercises can fall short in empowering stakeholders' ownership in the decision-making process required for a transformative change (Voinov et al., 2016) since model-based decision-making runs the risk of value disagreement between stakeholders involved, reducing the model's usefulness. For example, in a multi-actor environment, stakeholders may disagree on model conceptualization, structure, and critical input assumptions, especially if the proposed transition risk assessment approach is novel in the field. As a result, the stakeholders could abandon the model as a tool used for decision-making.

Participatory modeling is useful in addressing the shortcomings of a model-based decision-making process with a diverse stakeholder group. Participatory modeling aims to involve stakeholder groups early in the modeling process to maximize stakeholder buy-in (van Bruggen et al., 2019; Voinov et al., 2016) through knowledge sharing and permeation across different functions. The participatory modeling method typically applies in settings where stakeholders' alignment on model input is essential. Some examples of participatory modeling include climate change policy assessment, techno-economic assessment, and game design (Buchbinder et al., 2020; van Bruggen et al., 2019; Voinov et al., 2016).

3.2.2 Stakeholder analysis

A simple stakeholder analysis analyzes and documents the group's demographic, relevant experiences, and functions. They are the experts in Investment Research, Sustainable Investing (SI) Research, and the Active Ownership team. The Investment Research team is further split into the equity and credits research team in the heavy industries and mobility sector. They assess and make investment decisions pertinent to corporate stocks and bonds in the auto sector. The SI research team assesses ESG issues, corporate responsibility, and sustainability research based on key technology and policy developments. As for the Active Ownership team, their objective is to engage with investee companies combining findings from the investment and SI research team to steer corporate agendas. The summarized stakeholder analysis is shown in *Figure 10*.

Figure 10: Stakeholder typology showing the functions present within the asset management organization as part of the investment decision-making process



As a whole, the team's combined experience is close to 110 years, split between 7 experts. The longest tenure is 30 years, and the shortest is just one year (both in SI research). To provide some cultural background on the experts, four were Dutch, 1 Iranian, 1 Italian, and 1 Swiss. Out of the 7, 3 are Chartered Financial Analyst (Level 3) charter holders, and 2 hold post-doctorate degrees and research experience in physical sciences and sustainability-related fields. The gender ratio between males and females is 7:2, which is far higher than the industry average of 10:1 (Well, 2021).

3.3 Building a techno-economic assessment model for car OEMs with expert stakeholders

This section describes the steps that will be taken to enable a participatory modeling process using a techno-economic assessment model. I propose a five steps approach used in participatory modeling adapted from "Tools and Methods in Participatory Modeling: Selecting the Right Tool for the Job (Voinov et al., 2018). The proposed steps are introduced to set up a formal, structured process to guide the modeling process and evaluate the model's outcome. communication.

Step 1: Fact-finding

There is a significant sectorial knowledge gap in the initial stage, especially on key drivers in climate risk assessment, operationalization, key definitions agreement, and overall scoping. As a result, the process mainly focuses on literature review, speaking to internal research team members within the Sustainable Investing Team, and reiterating research questions. At this stage, a draft timeline drives the necessary deliverables before moving to the extended groups of stakeholders.

Step 2: Process orchestration setup

Process orchestration provides stakeholders with an overview of the steps that the research will take. It helps keep the research process organized, managed, monitored, and reported. Presentation software, brainstorming, Visual aids, workshops, and the Teams software ensure effective communication throughout the research process. At this stage, the research timeline is finalized, and extended to include the full scope. The communication with stakeholders is done formally and informally through in-person chats or scheduled workshops.

Step 3: Qualitative modeling and conceptualizing transition risk

Qualitative modeling is used here to convey critical relationships between various drivers to the participants. CLD and driver trees are used to communicate and decompose driver relationships. Additionally, scenario building (SB) is introduced to allow stakeholders to agree on baseline scenarios. At this stage, the participants agree upon the best modeling methodology based on applicability and tool interoperability. A spreadsheet program is unanimously agreed as the tool of choice, and the proposal of a techno-economic model is the same.

Step 4: Quantitative modeling

Step 4 extends the work in step 3 and builds the quantitative model following the model dynamics setup. In this step, data gathering is heavy, and much work is put into scrutinizing data integrity on data sources, accuracy, and representation. The assumptions attributed to model dynamics and data parameters could present significant debate within the team. Therefore, the assumptions are tabled and documented carefully. Lastly, a sensitivity analysis is built to strengthen model confidence by challenging fundamental assumptions. The sensitivity model is built in an open format, where the users could test the inputs exploratorily.

Step 5: Final model feedback using a semi-structured interview

The research and modeling process gathers a large number of interactions between participants. However, these interactions may not be fully documented, despite valuable input from experts throughout the process. Additionally, the presentations and workshops do not gather feedback on the process itself. Therefore, a semi-structured interview gathers the participants' input on the model outcome and potential.

Complementing the model building with a use case

In tandem with the five-step process, the research participants chose Volkswagen AG, the largest OEM globally by revenue, as the research case study to test the model structure and output.

3.4 Semi-structured interview setup for research evaluation

Evaluating the success/ failure of the participatory modeling process requires feedback from key stakeholders. A semi-structured interview technique can gather feedback from expert stakeholders from various functional backgrounds (van Bruggen et al., 2019). The technique is suitable because the surveyed group is small but diverse in functions, coupled with an open-question requirement to understand the novelty of the applied modeling process (Adams, 2015).

3.4.1 Methodology

I refer to the step-wise framework to design and conduct semi-structured interviews with the participating expert stakeholders (Adams, 2015). The method is explicitly applied post-delivery of the TEA model to seek feedback. There are four steps to ensure a structured process. First, the participatory modeling stakeholders were shortlisted, and an interview was scheduled for them, with the duration of the sessions lasting 30 minutes each. Second, for each interviewed stakeholder, an agenda and interview guide tailored to their functions are provided. Third, the interview is conducted virtually through text exchange or live using virtual video conferencing with the stakeholders. Fourth, written notes were taken for live interviews, and finally, the transcribed responses were reverted to the interviewees for accuracy verification. Fourth, the interviews were compiled, analyzed, and discussed, including limitations.

3.4.2 Interview questions

The interview questions are dedicated to eliciting comments specific to the expertise of the stakeholders. The questions consider the model output integration potential in the investment decision process and investment risks for the investment team. The approach between the current ESG metrics against the proposed risk approach is also explored to compare limitations and advantages.

The interview focuses on the future modeling approaches investors can use in transition risk investing for the SI research team. They will maintain the model and explore applying the current methodology to other sectors. Significantly, the focus is on the reflection of current work against relevant previous work within the team and looking forward to how the current modeling process will change to better align with the interests of other teams. In addition, the Active Ownership team emphasizes understanding how the output can be used in climate-related engagement to initiate dialogues on corporate climate strategy, consistent with the code of being a responsible investor (Belsom et al., 2019).

Lastly, an extra emphasis is put on model confidence building to determine if the sensitivity analysis built-in is sufficient to inform the investment decision-making process.

Investment team

1. What do you think of the potential for financial risk integration using *the model?*
2. How do you think this model compares mutual exclusivity (overlap of measured risks in measurement methodology) to other climate risk indicators such as MSCI, GEVA, and RobecoSAM?
3. In terms of transition risk, is the exhaustiveness appropriate with the measured scope, i.e., committed capital risk and policy risk?
4. What do you think about the sensitivity analysis setup? Is it sufficient to build confidence?

5. What about speculative assumptions to test, i.e., increasing social costs, battery costs projection?

SI Research team

1. Compared to the previous work(s), what did you learn?
2. How will you change your approach to stakeholder communication in the future?
3. How will you build model confidence when communicating to other stakeholders?

Active Ownership team

1. How will this tool assist your engagement activities with car companies?
2. How does the outcome of this tool compare to other climate risks assessment tools, i.e., ESG ratings?
3. How should the model build confidence in order to be useful?

4 Techno-economic assessment model for auto-sector transition

Ensuring model replicability and transparency is critical for knowledge integrity and sharing. Therefore, this chapter describes the model architecture, dynamics, and assumptions. First, the transition risk model boundary is established. Second, the model architecture will present and describe the relationship between the key components present in the model (Figure 13). Third, the model dynamics will detail the relationship within and between each component and provide numerical explanations as support. Fourth, the fundamental assumptions present in the model are listed and motivated. Overall, this chapter answers the third sub-research question:

*"**How to conceptualize, operationalize and assess the transition risk in the auto sector using a techno-economic assessment model?** "*

4.1 Transition risk scoping in the auto-sector

The auto-manufacturing value chain comprises upstream and downstream segments. Auto manufacturers, auto parts, and material suppliers operate in the upstream segment, and the downstream segment includes sales and distribution parties such as retailers and transport companies.

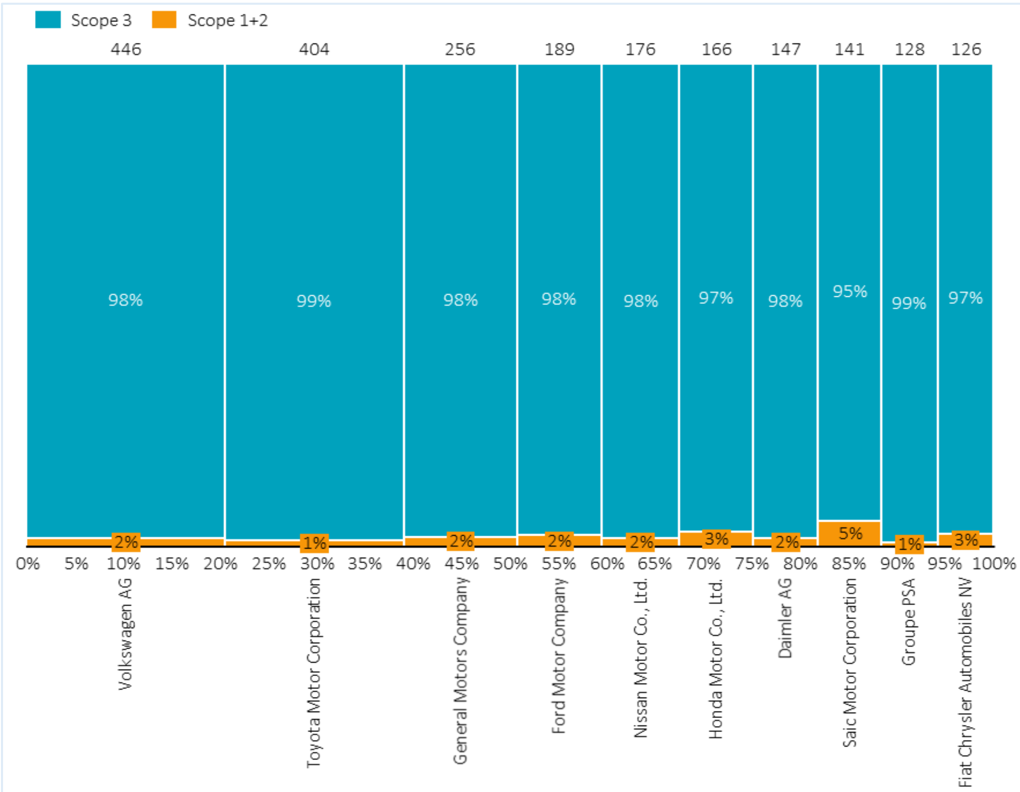
This research focuses on auto-manufacturers (OEMs) in the passenger car sector because OEMs are the main actors capable of initiating transition strategies. Therefore, the coverage is limited to OEMs producing light-duty vehicles or passenger cars. Further, the definition of light-duty vehicles follows the EU Worldwide Harmonized Light Vehicles Test Procedure, including passenger cars, mini-vans, and SUVs[8].

Corporations report on scopes 1, 2, and 3 emissions following the Greenhouse Gas (GHG) Protocol reporting standard (WBCSD & WRI, 2012). Scope 1 & 2 covers direct GHG emissions and electricity indirect GHG emissions. Whereas scope 3 covers indirect emissions and auto manufacturers that fall under product use phase emissions (WBCSD & WRI, 2012). Current reporting shows that OEMs' scope 3 use phase emissions contribute to 98% of CO_2 emissions on average, see *Figure 11*. For

[8] Auto parts and material supplies, vans, trucks, and 2-3-wheeler manufacturers are excluded from the definition of passenger car OEMs. This is because auto parts and material suppliers do not contribute emissions directly to the product sold, but to the manufacturing process. Heavier vehicles used for goods transport use a different carbon intensity metric, where tonnage of goods/ number of passengers transported per km are considered. For 2-3 wheelers, the emissions intensity is much lower, and there is also limited reporting standards on them.

that reason, the model ignores Scope 1 & 2 emissions and focuses only on Scope 3 emissions, which is also in line with the EU OEM carbon intensity assessment standard.

Figure 11: Top 10 highest emitting car manufacturers globally, absolute emissions shown in MT, data extracted from CDP

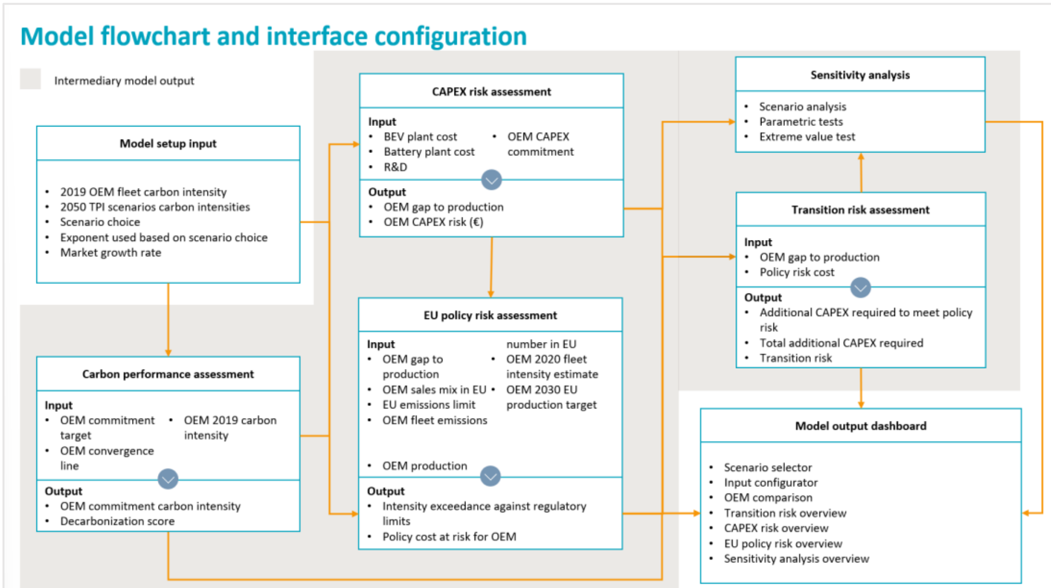


4.2 Auto-sector transition risk model architecture

The model has an input, intermediary output, and output component to assess transition risk. The model setup input provides and captures the baseline condition for OEM carbon data, scenario choices, transition speed, and OEM growth rate. For this research, the model setup is limited to a 2 degrees climate pathway scenario, which is the consensus assessment scenario by participating stakeholders and aligns with expectations from current practitioners in the related field (Fulton et al., 2013; Pianta et al., 2021).

The intermediary output consists of a carbon performance assessment, a carbon performance assessment, a CAPEX risk assessment, an EU policy risk assessment, a transition risk assessment, and a sensitivity analysis. Finally, each assessment's output is presented in the central model output dashboard that serves as the model's primary interface for user interaction.

Figure 12: Model flow diagram showing the model setup and the information flow from the model setup and input to the intermediary models and the model output dashboard.



Central to the model output is the transition risk definition, which is defined as:

$$OEM\ Transition\ risk = Additional\ CAPEX\ required\ for\ BEV - Policy\ risk\ cost$$

Additional CAPEX risk required for BEV is defined as:

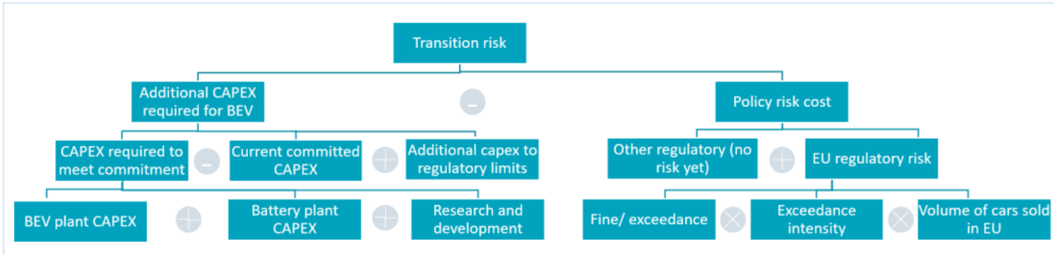
$$\begin{aligned} Additional\ CAPEX\ required\ for\ BEV \\ &= CAPEX\ required\ to\ meet\ commitment \\ &-\ Current\ committed\ CAPEX \\ &+ Additional\ CAPEX\ to\ meet\ regulatory\ limits \end{aligned}$$

The policy risk cost of an OEM is defined as:

$$Policy\ risk\ cost = Other\ regulatory\ risk + EU\ regulatory\ risk$$

Figure 13 shows the primary model conceptualization of the transition risk, presented using a model decomposition diagram with additional two layers of intermediary output that informs the construction of the first layer components, explained next.

Figure 13: Transition risk conceptualized with a decomposition into capital and policy risk elements with additional supporting layers that form the relationship within the model



The detailed formulation of the model composition is shared in the sub-model descriptions in section 4.7, and the complete model decomposition is shown in the appendix in section 0.

4.3 Input data gathering, processing, and manipulation

The model framework assesses the transition risks of major car manufacturers in the world. The transition pathways follow the climate target OEMs set in the future. Companies also disclose their intended capital expenditure (CAPEX) to reach those targets. For a detailed data description, refer to section 0. There are 20 OEMs included in the carbon performance assessment and 1 OEM (Volkswagen AG) in the CAPEX and policy risk assessments.

Carbon performance assessment data

Carbon intensity and climate commitment targets are needed to chart the carbon intensity pathways for the companies covered. The 2019 carbon intensity data is available through the Transition Initiative Pathway's website and cross-checked with the International Council on Clean Transportation's (ICCT) reports. The commitment targets are gathered through primary sources, i.e., OEM's corporate websites, with the aid of search engines using keywords of "corporate name", "climate target", and "2030" or "2050".

There are instances where the corporations report intensity data in an unclear manner. For example, companies could use a random base year as a reference point for intensity reduction achieved but do not report on the carbon intensity itself. Therefore, it is helpful to conduct additional manual research on other reference years to triangulate and derive the carbon intensity figure. This approach applies to Honda, where the data refers to percentage reduction based on 2005 data.

CAPEX risk assessment data

CAPEX risk is a techno-economic assessment (TEA) that translates the forward climate target of companies into production requirement and subsequently derive the investment amount needed to reach those targets set. The approach derives the investment amount needed by first finding the expected production target. A detailed explanation of the model dynamics is found in section 4.7.1.

The data gathering process is similar to the previous methods. Based on the typical plant production capacities, I induce the production plant costs for battery and battery electric cars (BEVs). The cost of the plants is available online, using a search engine (Google) and keywords such as "Corporate Name", "BEV plant cost", "Battery plant cost". The data is available through the OEM website for CAPEX committed, as significant investments are announced routinely to investment analysts to ensure reporting transparency.

Policy risk assessment data

I first started with the search engine to understand the policy framework available in major car markets. The report from the International Energy Agency that summarizes the policy outlook for different countries provided a filter to focus on the European policy framework.

For the European policy framework, I relied on publically available input from the European Commission and the ICCT. The additional inputs are the regulatory fines limit, fines per gCO_2/km exceeded, value limit curve, OEM's European carbon intensity, and the average fleet weight; these data are available through the ICCT report (Mock, 2019). I relied on the corporate website and their spreadsheet production database for production volume information in the EU to determine the latest available EU production figure.

4.4 Model setup, input, and output dashboard

4.4.1 Model output and dashboard

The dashboard sheet presents the model output and acts as an interactive interface for users to set up model assumptions. This setup allows the users to experience the model with a user-friendly interface that provides real-time results, much like software. The dashboard also provides a model setup input for users to choose which OEMs to assess, climate scenario, climate transition speed, and the market growth rate. The selections will compute the primary output- the transition risk, and the intermediary outputs- the CAPEX and policy risks. The results from the sensitivity analysis also accompany the output.

4.5 Operationalization

4.5.1 Measuring auto sector carbon intensity using gCO_2/ km

Ensuring standardized metric operationalization is essential to ensure comparability. Therefore, the research operationalizes the transition risk metric using a carbon performance measured in grams of carbon dioxide emitted per kilometer (gCO_2/km) in New European Driving Cycle (NEDC) standards. This measurement is in-line with stipulated standards reported in the European Union (European Commission, 2021)[9].

[9] Note that the WLTP standard will replace the NEDC standard in 2021, but empirical conversions are available, so they are interchangeable (Fontaras et al., 2017). Other jurisdictions may use their standards, but companies usually report gCO_2/km in NEDC terms.

4.5.2 Operationalizing transition risk using cash flow

The transition risk first operationalizes climate targets, but a translation to financial metrics is required to bridge physical risk into investment decision-making. Therefore, I use currency with Euro (€) as the commonly denoted fiat metric.

I use cash flow to measure the transition risk because of the common accounting standards used in corporate financial valuations. For example, the cash flow represents the capital expenditure for the transition investment, which shows in the firm's cash flow statement. Moreover, the OEMs face policy risks in cash, hence also reflected in the firm's cash flow statement

4.5.3 Defining model boundary

- The timescale for the model is from t_n = 2019-2030, with Δt = 1 year because this is a standard reporting and assessment interval for policy reviews and corporate commitment coverage.
- For regulatory coverage, the policies are Euro-centric, given that the European Commission is the most advanced in enforcing financial penalties for auto corporations.
- 8 out of 10 companies covered set mid-term emissions reduction commitment in 2030. The stakeholders agree that the uncertainty further than 2030 will be too much. Therefore, it makes sense to take this as the reference point of assessment. If companies are with further targets, i.e.,

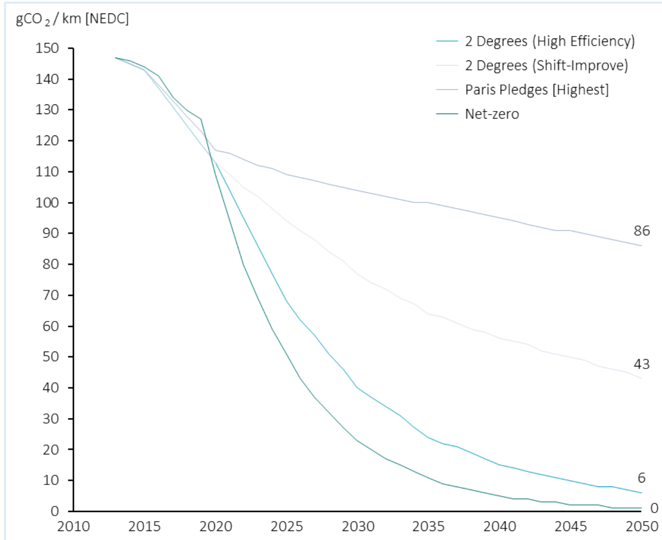
4.5.4 Selecting a climate scenario pathway

The climate scenario pathway connects climate science into the assessment framework by defining the maximum carbon intensity boundary for OEMs to transition by 2050. In other words, the climate scenario pathways allow the OEM to understand how much emissions they need to reduce. The climate scenario pathway selected is six grams of carbon dioxide per kilometer traveled (gCO_2/km) in 2050.

Having a baseline for the OEMs to converge towards is crucial as it points to a clear objective, especially when working with a diverse stakeholder group. The Transition Pathway Initiative provides the temperature pathway against the climate scenario in the auto sector, measured in gCO_2/km [NEDC]. A convergence method determines the firm-level carbon intensity in 2050. For the research, a convergence pathway is modeled using an exponential decay function towards their endpoints in 2050.

There are four different scenarios, three from the Transition Pathway Initiative (TPI) and an additional Net-Zero scenario modeled using an exponential function (see *Figure 14*). The reference case for the scenarios is derived from the IEA global energy model, based on IPCC scenarios (Gebler et al., 2020; IEA, 2020a; IPCC, 2021).

Figure 14: TPI climate temperature pathways for firm-level convergence assessment



- **Paris Pledge** [86 gCO_2/km]

  The Paris Agreement considers carbon emissions reduction pledges at the country-level, also known as the Nationally Determined Contributions (NDCs). In this scenario, the aggregated ambition of countries' emissions is insufficient to limit warming to 2°C. This scenario assumes full implementation of currently stated national ambitions. Analogically, this scenario is closer to a "business-as-usual" pathway.

- **Avoid-Shift-Improve** [43 gCO_2/km]

  The Avoid-Shift-Improve scenario is a 2 degrees limit pathway. It gives more weight to increasing consumer awareness that drives down travel demand altogether (avoid), which a slower shift to more energy-efficient modes of travel (shift), and at the same time expects improvements in higher efficiency transport modes.

- **High-Efficiency** [6 gCO_2/km]

  The High-Efficiency scenario prioritizes rapid technologically feasible shift and development towards low carbon intensity vehicles. The resultant temperature pathway is the lowest (<2°C) amongst the three benchmark pathways provided by the TPI. As mentioned, this scenario is used as the baseline to drive further analysis with the participating researchers.

- **Net-Zero** [0 gCO_2/km]

  The Net Zero Emissions by 2050 case examines what more would be needed beyond the TPI scenarios over the next ten years to put global CO2 emissions on a pathway to net zero emissions by 2050. The Net-Zero pathway is modeled using an exponential decay function to reach a near-zero asymptote (y~0). It is in line with the pathways used by the Intergovernmental Panel on Climate Change for the Special Report on Global Warming of 1.5 °C (Magnan et al., 2021).

In the model, scenario options are presented in a data table. Look-up functions connecting the scenario data table to scenario selection toggle allow users to switch to either of the scenarios provided to test different climate risk boundaries.

4.6 Carbon performance assessment

A carbon performance assessment model assesses the carbon intensity gap between OEMs and their temperature pathways. In addition, a comparative scoring examining current and future carbon intensity is developed for the stakeholders to gain an overview of firm-level carbon performance. Finally, the model output sheet presents the carbon performance assessment.

The carbon performance assessment model gives an overview to the model users on the current and future carbon performance level of OEMs by assessing the gap between (i) the current corporate carbon intensity, (ii) the future committed intensity against their convergence pathways. This overview helps the model users understand the OEMs' carbon performance before selecting an OEM for the transition risk assessment.

Convergence pathways are modeled for each firm in scope using an exponential decay function to meet the six gCO_2/km pathway in 2050. The exponential decay function is realistic for modeling the convergence pathways because the stakeholders agreed that the sector has strong market demand, high technological maturity level, and infrastructure readiness; the exponential decay function used to determine the carbon intensity C_{t_n} is :

$$C_{t_n} = C_{t_1}(1 + r)^{(t_n - t_1)}$$

Where C_{t_n} is the OEM's carbon intensity at the time t_n, n is the timestep, r is the exponential decay rate, determined using the end carbon intensity over the initial carbon intensity, to the roots from the difference in timesteps, denoted below:

$$r = \frac{C_{t_{32}}^{\frac{1}{t_{32} - t_1}}}{C_{t_1}}$$

Next, the commitment lines of the OEMs are plotted to assess the OEM's climate reduction target or commitment paths. The commitment path is computed using a linear interpolation between target emissions over the timesteps covered, where the carbon intensity, C_{t_n} from commitment path is:

$$C_{t_n} = C_{t_{n-1}} \times m_i$$

Where C_{t_n} is the OEM's carbon intensity at the time t_n, n is timestep, m_i is the gradient to interpolate the carbon intensity linearly:

$$m_{i_{s,m,l}} = \frac{T_i - T_j}{t_i - t_j} \quad , \qquad T_i > T_j;\ C_i > C_j;\ s > m > l$$

Where T_i is the OEM's target carbon intensity at target intensities T_i and T_j; with s, m, l indicating short, medium, and long term targets, if available. t_i and t_j are the corresponding timesteps to T_i and T_j.The short, medium, and long-term targets are split into grouped year ranges of 2019-2025, 2026-2029, and 2030-2050. The data are categorized because OEMs and larger business communities set short, medium, and long-term targets in such a fashion. The gradient function computes the gradient m_i that falls between each grouped year range which plots the decline of the target emissions. The next target is used to compute the declining gradient if a data gap exists between the grouped year ranges. This condition requires a boolean logic to determine the availability of short, medium, and long-term gradients. The boolean logic in the model relies on IF Functions and dynamic lookup using XLOOKUP.

This commitment path calculated enables comparison between the commitment paths set by the OEMs, and therefore the model users can glean overview information from the dashboard.

Lastly, the companies are scored according to the performance scoring metrics co-created with the stakeholders (see Appendix 0). This output gives the stakeholders the first basis for comparing the OEMs and engagement with portfolio companies.

4.7 Cash flow risk estimation

As alluded to, the transition risk assessment operationalizes cash flow as the model output measurement- termed the cash flow risk. Cash flow risk is further split into two categories, measuring technological and policy risks combined into a techno-economic assessment model.

The technological risk is operationalized as a transition capital expenditure (CAPEX). The model measures the capital surplus or shortfall that an OEM faces following the TEA. The primary output is the cash flow risk output that measures the additional investments (positive or negative output, indicating shortfall or surplus, respectively) auto manufacturers require to produce electric vehicles. The TEA takes an investment/ annual capacity approach, which means that the surplus or shortfall found will translate into the annual production capability for the OEM. The annual production capability is an intermediary output from the model. The percentage surplus or shortage output found from the committed CAPEX level serves as an input for the policy risk assessment.

The policy risk measures the potential fines an OEM could face should they exceed the legal limits of average fleet emissions in the EU. First, the average fleet carbon intensity is projected and compared against the OEM's emission intensity limit for this model. Then, the surplus beyond the emission limit is translated into cash flow risk by taking the product between the number of cars sold in the EU, the emissions limit exceeded, and the current fine of 95 €/ [gCO_2/km].

Further, a common growth rate connects the two risk categories. There are no feedback loops between the model components. The following sub-sections will dive into the model dynamics to detail how the transition risk is computed.

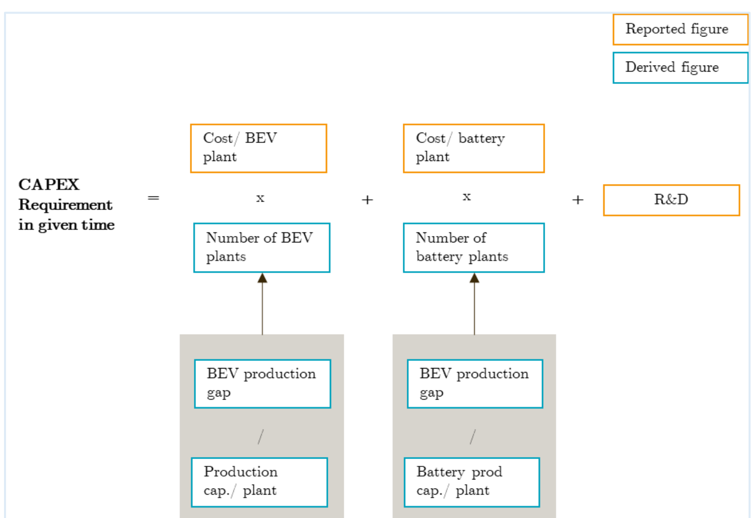
4.7.1 CAPEX risk assessment

On top of the climate commitments, OEMs are also disclosing the CAPEX amount they are committing to the balance sheet towards transitioning their business model. However, this committed capital is only a headline without detailed disclosure on exact expenditure. Consequently, this poses risks for investors if OEMs fail to achieve their target and result in cash flow and reputational damages.

CAPEX risk is defined as the additional CAPEX required to meet firm-level production target, compared to the current CAPEX stipulated by the company (see *Figure 15*). The first step is to operationalize the climate commitment into the future. Corporations usually provide short-term, mid-term, or both production targets for 2025 and 2030, respectively. Then, the targets set are operationalized into carbon intensity in the Carbon Performance Assessment. For example, a 2030 target of 30% emissions reduction based on 2019 emissions will result in 30% lower carbon intensity in 2030 as input data.

Next, a high-level technological assessment assesses the key components needed for the transition. Again, the approach is bottom-up, considering the technical requirements of BEV production capacity and battery plant production capacity. Finally, research and development are apportioned based on the commitment statements released by OEMs.

Figure 15: Estimating OEM specific CAPEX based on key spending components and capacity requirements from stated commitment



To do so, I project into 2030 the production target of the OEM using a sector-specific historical compounding annualized growth rate of 2% and then multiplied by the BEV commitment sales target stipulated.

Additionally, I included an installed production capacity estimation, where the current available annual production capacity is adjusted to reflect future production gap; the equation is stylized below:

$$\text{Production gap} = \text{Final required annualized production capacity} \\ - \text{Current annualized production capacity}$$

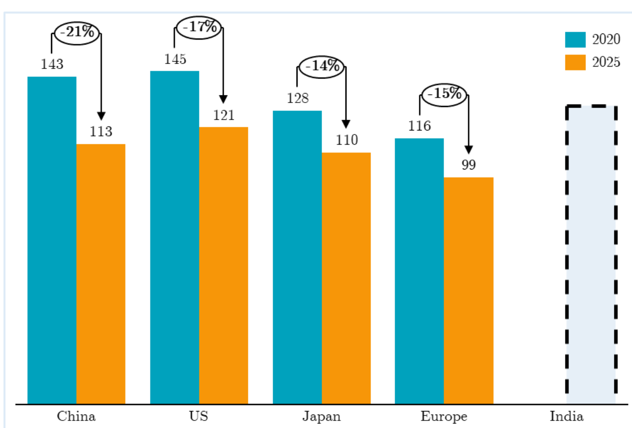
Then the annual capital requirement is calculated based on the total number of, I rely upon news sources and corporate press releases as the data input for the costs of BEV and battery plant per production capacity. As for research and development, the input relies on the specified apportioned figure, depending on how the OEMs structure their capital expenditure.

4.7.2 Policy risk assessment

Climate policy path dependency reduces uncertainty but could introduce more policy risks to corporations. The policy risks usually come in the form of policy interventions administered using various policy interventions. Chapter 3 showed countries committing more decisive climate actions since Paris, where countries are beginning to introduce regulatory requirements on polluting industries in their commitment. This phenomenon is especially evident in the EU. They introduced various instruments such as the European Border Tax, Carbon Cap and Trade system, subsidies, investment schemes for climate techs, et cetera.

The emissions intensity limit poses a financial risk to the corporations in the auto sector. Therefore, this instrument helps reduce emissions as it effectively forces an OEM to reduce average fleet intensity by introducing battery electric vehicles or reducing internal combustion engine vehicles. In addition, nation-states such as China, the US, EU, Japan, and India have introduced some forms of emissions target (IEA, 2021) (see *Figure 16*).

Figure 16: Summarized emissions target of major passenger car consumption market showing emissions reduction from 2020-2025



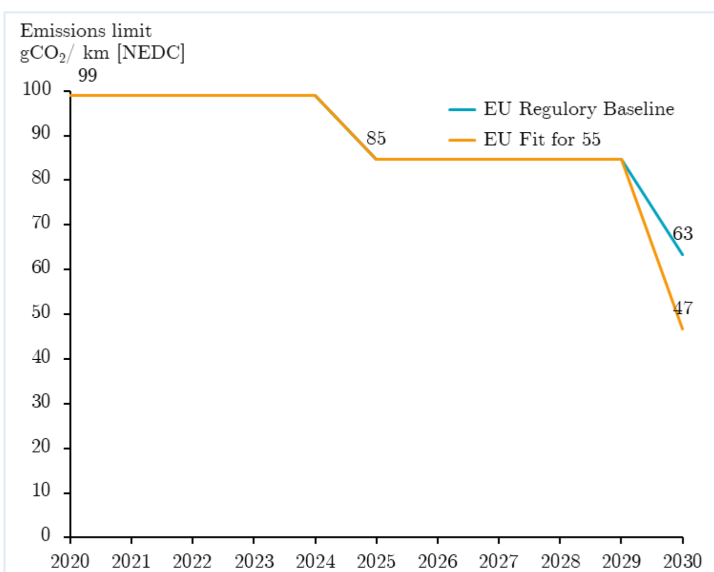
However, the EU is the only jurisdiction body that enforces an emissions intensity limit (see *Figure 17*). Therefore, a deeper focus is on the European market to understand the underlying policy risk(s).

Figure 17: Summarized emissions target/ ambitions [NEDC] by key passenger car countries (IEA, 2021)[10]

Countries	Phase Out ICE Year	2020 Intensity Target	2025 Intensity Target	2030 Intensity Target	2025 ZEV Target	2030 ZEV Target	Explicit Fine?	Remarks
China	2035	117	93	**~35**	20%	30%	**N**	Not strict
India	N	n.a.	n.a.	**~80**	n.a.	**30%**	**N**	**n.a.**
US	N	119	99	**~47.5**	partial[1]	partial[1]	**Y**	Not strict
Japan	2035	105	90	**~60**	n.a.	70%	**N**	**n.a.**
Europe	2050	95	81	**59.4**	15%	35%	**Y**	**n.a.**

For passenger car fleets sold in the EU, a 95 €/ [gCO_2/ km] fine is imposed on average fleet intensity exceeded with progressive limits adjusted every five years from 2020. Figure 18 shows the policy scenarios OEMs in the European Union face as the EU ramps up her lead in global climate policy. The policy risk assessment incorporates the latest policy proposals. It operationalizes them using a methodology (shown in the next section) that includes the proposed, more aggressive target as part of the risk assessment.

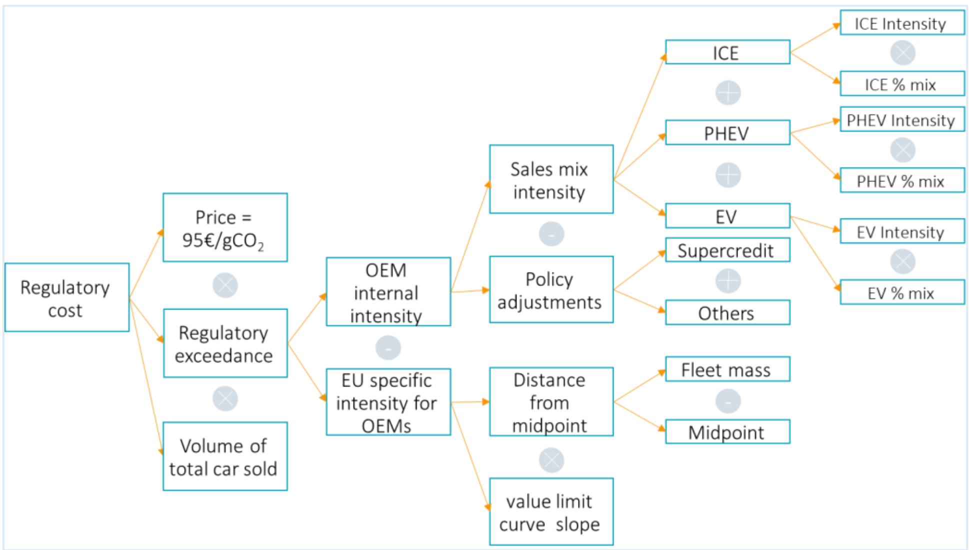
Figure 18: EU auto emissions limit regulatory pathways up to 2030 for baseline and EU "Fit for 55" policy scenarios



4.7.2.1 *A policy risk model for the EU*

Nonetheless, modeling policy risk is delicate as many sub-branches within the policy framework promote intensity reduction, such as the super-credit, eco-innovation credit, and the pooling mechanism. For the policy risk model, the timescale, t_n = 2019-2030, with $\Delta t = 1$, where n represents the year's count.

Figure 19: The EU passenger car manufacturer's emissions intensity limit regulatory framework decomposed for firm-level policy risk assessment



Policy risk here is defined as regulatory cost, a product function between regulatory exceedance, carbon price, and volume of total cars sold in the EU. Figure 19 shows the decomposed policy framework used to measure policy risk for OEMs. In this section, I draw the focus on the *regulatory exceedance* parameter. The *regulatory exceedance* parameter is defined as:

$$\text{Regulatory exceedance} = \text{OEM internal intensity} - \text{EU specific intensity for OEMs}$$

Further, the OEM internal intensity is defined as:

$$\text{OEM internal intensity} = \text{EU sales mix intensity} - \text{EU policy adjustments}$$

The EU sales mix intensity is defined as:

$$\text{EU sales mix intensity} = (1 - \text{share of BEVs sold}) \times \text{average ICE fleet intensity}$$

The first OEM average fleet intensity is derived using an adjusted average ICE fleet intensity using a goal seek function that iteratively interpolates the closest average ICE intensity required to reach a reported 99.8 gCO_2/km fleet intensity. The following average fleet intensities assume no changes in eco-innovation and pooling mechanisms, thus relying on the first average fleet intensity. This adjustment

[10] ZEV denotes Zero Emissions Vehicle, which in this research is assumed the same as a BEV

accounts for the pooling mechanism and the eco-innovation system dependent on corporate reporting and is subjected to scrutiny by the European Commission (EC). However, it takes time to report the results, and therefore, the average ICE fleet intensity will have a lag in the model.

The EU policy adjustment is defined as:

$$\text{EU policy adjustments} = \text{supercredit} + \text{eco-innovation} + \text{pooling mechanism}$$

Moreover, the EU specific intensity for OEMs, E is defined as:

$$\mathrm{E} = E_0 + \alpha(M - M_0)$$

Where E_0 is the EU-specific CO_2 intensity target for an OEM, α is the slope of the limit value curve, M is the annualized average mass of the OEM's vehicle fleet from registered sales in EU, and M_0 is the average fleet mass of all manufacturers in the pool[11].

- **Super-credit**

  Super-credit is a capped intensity reduction mechanism for OEMs to sell more electric or hybrid cars. Under the super-credit, the intensity reduction of the mentioned car types is counted extra, with 2020 and 2021 being 2x, 2022 being 1.67x, and 2023 being 1.33x. The super credit system is phased out from 2024 onwards.

- **Eco-innovation credit**

  Eco-innovation credit applies to OEMs who can report improvement in their ICE drivetrain emissions level by introducing more environmentally friendly technologies. Manufacturers can usually apply up to 7gCO_2/ km reduction, which is significant considering that Volkswagen AG exceeded emissions by 0.5gCO2/ km, resulting in a ~€160M fine. But, eco-innovations usually have minimal intensity reduction (Tietge et al., 2021) and are contingent on the EC's approval. This feature is reflected in the adjusted ICE fleet intensity as an input used in the model.

- **Pooling system**

  Lastly, there is the pooling system, where the OEMs can pool together their production capacity based on the emissions budget and intensity level. However, the pooling mechanism's reporting is flexible and difficult to exercise. Therefore it is not included in the policy assessment and is adjusted according to the corporate report.

[11] Note that α is a fixed gradient defined by the EC dependent on the duration of M_0, where M_0 is updated on a triennial basis (but done biannually starting 2024). These data are available through the EC website and the ICCT.

4.8 Ensuring model "usefulness"

A model in decision-making is but a boundary object used to negotiate an outcome between the stakeholders, and they could be built to be useless (van Bruggen et al., 2019). A model built poorly without considering the stakeholders will often fail to provide continuity in its use. In some situations, a model fails to imbue confidence for the users given the combinations of conceptual, structural, and parametric errors. Additionally, some models are built without considering the target audience's interoperability, using overtly sophisticated or incompatible tools or both. This section describes the steps taken to ensure that the model is useful by considering a model's fit for purpose, user confidence building, and model use continuity.

4.8.1 Fit for purpose

Broadly, the model serves two purposes. First, the model provides an interactive overview of sector-level carbon performance using a *decarbonization score*. The decarbonization score is supplemented by the sectorial comparison between various firms and the convergence temperature pathways unique to each firm. This comparison is useful for the model users, regardless of their functions, to explore the carbon intensity gaps that the firms will need to overcome to reach specific temperature pathways.

Second, the model provides a risk assessment methodology on top of the user-friendly features. The risk assessment feature is shown alongside the carbon performance assessment dashboard to assess companies in a qualitative (commitment and targets) and quantitative (technology and policy drivers) manner.

Supporting both purposes are the various user-friendly features built in the spreadsheet model. For example, they can select scenario setup, adjust firm-level transition rate, and explore future scenarios using variables.

4.8.2 User model confidence-building and model validity

Validation of the model is essential for the modelers to pinpoint the fallacies and weaknesses. Therefore, the modelers must improve the confidence of models through validation tests. Without confidence in the model, no insights can stand firm and thus fail to influence decision-making. Moreover, by eliciting the weaknesses in the model, the model user can understand the purpose of the model and how it should be applied to test the hypothesis. Inarguably, the model will have satisfied the users' need to answer the main research question. Key elements to communicate model confidence are a representative conceptualization, adequate model structure, and robustness for assessments.

Representative conceptualization

Visual aids, numerical equations, informal chats, and workshops explain to participating stakeholders the model conceptualization (see *Figure 12*). The process is done step-wise, with conceptualizations of carbon performance assessment first presented, then the CAPEX risk assessment, and finally the policy risk assessment.

In the process, iterative feedback is gathered through the stakeholders to ensure that the representations provided are satisfactory.

Adequate model structure and robustness

The model inputs in the techno-economic assessment contain uncertainty and are subject to changing environments. The model must cope with these changes and prioritize key model drivers that influence the model outcome. An uncertainty analysis is used to test the model behavior and its robustness to strengthen user confidence further. For this, I rely on the works of (van der Spek et al., 2020), where the authors applied uncertainty analysis in a techno-economic model for Carbon Capture and Storage assessment. Through workshops with the participants, I prioritized the key inputs that the expert stakeholders consider the most relevant and provided features in the model to test local sensitivity using a parametric test, extreme value test, and scenario analysis. Lastly, VW's investor relations validated key outcomes and parameters within the techno-economic model with the latest information, strengthening the overall assumptions.

4.8.3 Model use continuity

The model should be continuously maintained and updated to reflect the accuracy in reality representation. Therefore, updating model input, altering the model structure, or both is necessary to reflect the latest reality. A few built-in features ensure the model is friendly to last into the future. First, the model is semi-autonomous, where a data input table provides the corporate production and climate commitment data applicable for all three assessments. Lookup functions are in place to automatically reflect any new input into the model; therefore, there are minimal moving parts. Secondly, a model manual is written for interested users. Third, written guidance is also present in each model section with clear formatting, labels, and description. Fourth, a data assessment section is set up to capture all input used in the techno-economic assessments and provide clear unit labels, sources, and input descriptions.

5 Results and findings

This chapter presents the findings following the techno-economic assessment model and includes the participatory process findings to succinctly the research process results.

The first part of the chapter presents the results from the carbon performance assessment, where companies are ranked qualitatively on their current and future carbon intensities. Second, the transition risk assessment results show the main model output, with Volkswagen as the use case. Moreover, the section analyzes the model and discusses insights derived from the intermediary and primary results. The next model confidence-building section communicates the sensitivity analysis results from the four techniques used. Finally, the chapter closes the discussion with an answer to question four of the sub-research question:

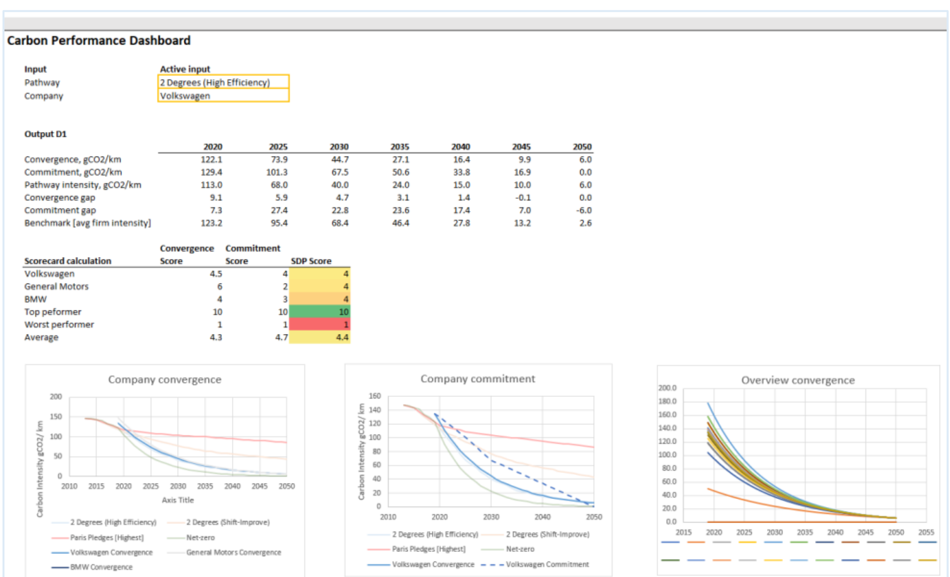
"What is the integration potential of the transition risk assessment tool in the context of a diverse expert stakeholder group?"

5.1 Carbon performance assessment tool

The carbon performance assessment aims to provide an overview of the key players in the auto sector globally for the stakeholders. The outcome from the assessment forms the first filter for the next step the model user can take to assess the companies further for firm-level transition risk.

In the overview tab of the spreadsheet model, a carbon performance dashboard is built for users to explore climate data related to OEMs in the auto sector. In addition, there are scenario selection features that allow users to modify the baseline scenarios for decarbonization score comparison.

Figure 20: Overview dashboard of the TEA model showing overall carbon performance of OEMs in coverage



Carbon Performance Dashboard

Input	Active input
Pathway	2 Degrees (High Efficiency)
Company	Volkswagen

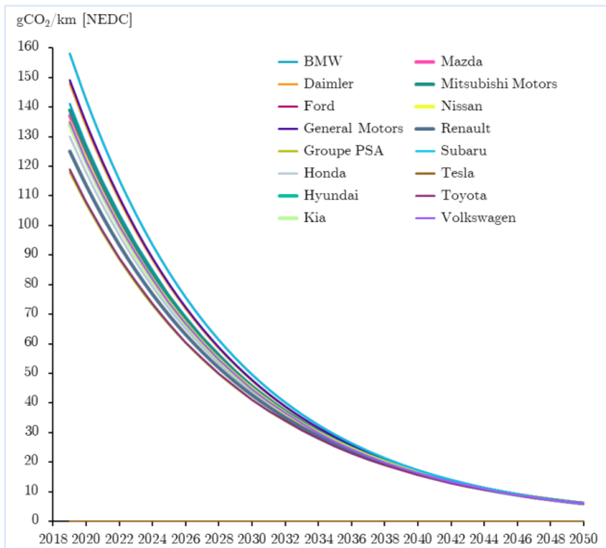
Output D1

	2020	2025	2030	2035	2040	2045	2050
Convergence, gCO2/km	122.1	73.9	44.7	27.1	16.4	9.9	6.0
Commitment, gCO2/km	129.4	101.3	67.5	50.6	33.8	16.9	0.0
Pathway intensity, gCO2/km	113.0	68.0	40.0	24.0	15.0	10.0	6.0
Convergence gap	9.1	5.9	4.7	3.1	1.4	-0.1	0.0
Commitment gap	7.3	27.4	22.8	23.6	17.4	7.0	-6.0
Benchmark [avg firm intensity]	123.2	95.4	68.4	46.4	27.8	13.2	2.6

Scorecard calculation	Convergence Score	Commitment Score	SDP Score
Volkswagen	4.5	4	4
General Motors	6	2	4
BMW	4	3	4
Top peformer	10	10	10
Worst performer	1	1	1
Average	4.3	4.7	4.4

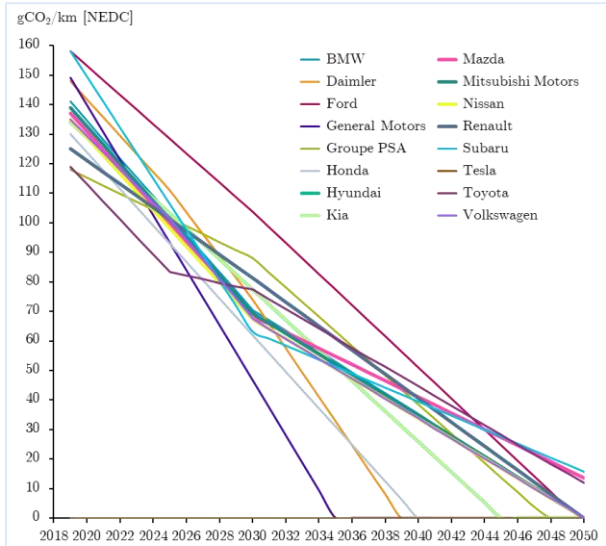
In *Figure 21*, 16 OEMs with climate targets are selected to show their climate convergence pathway based on the Transition Pathway Initiative's below 2-degree Celsius Shift-Improve scenario. The convergence line relies on an exponential decay function with a variable decay rate. Moreover, the current decay rate follows the closest climate pathway and is selected as the default decline rate. This rate depends on the subjective belief of the model user and should be consistent. The decay rate chosen forms the baseline for further co-creation with the participants in the subsequent steps.

Figure 21: Exponentially decaying firm-level carbon intensity requirement tells us that OEMs face a steep curve in order to meet an under 2°C scenario pathway



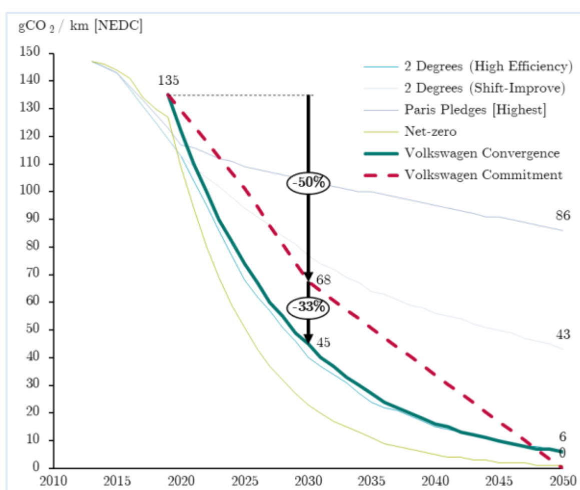
Next, the commitment targets of the 16 OEMs are plotted so that a peer comparison is available for the users to compare the climate target ambitions of various OEMs. *Figure 22* shows that all firms have some climate targets, but there are discrepancies between target granularity when examined from a time interval angle. Some OEMs choose to omit short-term goals or are still in the deliberation process to design one. All in all, this visual helps the model users to grasp the state of commitment for various companies quickly. There are options within the tool itself where the OEMs can be shortlisted and filtered out. This feature ensures that the model is user-friendly in the specific analysis process.

Figure 22: Firm-level climate commitment into 2050, showing a stark discrepancy in ambition levels between OEMs



The company chosen as a first case study to test model structure is Volkswagen AG (VW), shown in *Figure 23*. The baseline scenario selected is six gCO_2/ km and Volkswagen AG with a 135 gCO_2/ km carbon intensity in 2019. Volkswagen AG has a 50% sales target for battery cars with €36.5 Billion committed in capital expenditure towards 2025 (Volkswagen, 2020). This commitment results in a forward-looking carbon intensity of 67.5 gCO_2/ km in 2030. However, the convergence figure for Volkswagen is 45 gCO_2/ km, which means that Volkswagen is still has a 33% gap to be on par with the climate scenario, assuming that they can meet the 50% emission reduction target.

Figure 23: Convergence and commitment target line of Volkswagen AG, and comparison with climate scenarios by IPCC into 2050 showing how the progress necessary for Volkswagen to be on track for a below 2°C scenario



Finally, a decarbonization score is imposed on the shortlisted OEMs (see *Table 4*). OEMs without a commitment target are denoted with a null value. The score focuses on the OEMs' current relative carbon performance and their future commitment target relative to an arbitrary carbon intensity of 40 gCO_2/ km. The scores are provided based on an interpolated scale for current and future performances. Before attributing the scores, the scoring methodology was discussed in advance to gain agreement from the participating stakeholders within the SI research team. A 50/50 split gives both present (weight A) and future (weight B) scorings an equal weight, which reduces contentions on the weights allocation.

The research only examines scope 3 emission as stated earlier and awards electric car manufacturers with total points (see Tesla). Surprisingly, given the lax attitude of the US government on emissions policies, both companies with a perfect 10 in 2030 are American (General Motors and Tesla). The scoring methodology designates OEMs that score above five are good. On average, the OEMs score a 4.4, reflecting a below-desired performance.

Table 4: Forward-looking scoring methodology assessing the firm-level ambitiousness of climate targets

Firm name	2019 Intensity, gCO_2/ km	Weight A [50%]	Weight B [50%]	Decarbonization Score
BMW	141	3	5	4
Daimler	148	2	5	3.5
Ford	158	1	1	1
General Motors	149	2	10	6
Groupe PSA	118	7	1	4
Honda	130	5	6	5.5
Hyundai	134	4	3	3.5
Kia	134	4	3	3.5
Mazda	137	4	5	4.5
Mitsubishi Motors	139	3	5	4
Nissan	135	4	5	4.5
Renault	125	6	2	4
Subaru	158	1	7	4
Tesla	0	10	10	10
Toyota	119	6	2	4
Volkswagen	135	4	5	4.5

5.2 OEM-level transition risk assessment

Volkswagen AG (VW) is the studied company to assess its transition risk moving forward. In this section, the results of the transition risk are shared first, followed by the CAPEX and policy risk assessments. *Table 5* presents a transition risk summary at an OEM level for VW in 2025. The 1.27% base case gap to production target represents the CAPEX gap produced from the CAPEX risk assessment model.

There are three scenarios studied in 2025: the regulatory baseline of 81 gCO_2/ km, the convergence path for VW at 73.9 gCO_2/ km, and the convergence path for VW as the maximum policy risk boundary, because that would put VW on track towards a below 2°C pathway. The EU "Fit for 55" regulatory limit in 2025 is the same as the baseline, and therefore the minimum policy risk is representative of both scenarios.

Interestingly, having a commitment target does not always mean an OEM meets its emissions limit. The CAPEX gap to avoid fines shows the percentage of additional CAPEX required not to exceed emission limits at 1.51%. An iterative goal seek function determines the CAPEX gap when policy cost equals zero. The goal seek function works by approximating iteratively on the gap to production input until the policy cost is zero. The difference between the CAPEX gap to avoiding fine and the base case gap to production target produces the additional capacity required, assuming a 1:1 relationship between CAPEX and capacity. Multiplying the stipulated CAPEX amount of €36 billion with the total additional capacity required results in an adjusted CAPEX gap of €1 billion for VW.

Table 5: Transition risk summary showing minimum and maximum policy risk case in 2025 using a Goal Seek function

Input	**Base Case**
Company growth rate	2.00%
Gap to production	-1.27%
Min policy risk analysis in 2025 using Goal Seek	**Value**
CAPEX gap to avoiding fine, %	*1.51%*
Base Case gap to production target, %	-1.27%
Total additional capacity required, %	3%
Adjusted CAPEX gap, €	1,014,988,034
Policy cost at risk, €	1,427,856,660
Transition risk, €	-412,868,627
Emissions limit surplus equivalent, gCO_2/ km	1.1
Max policy risk analysis in 2025 using Goal Seek	**Value**
Base Case gap to production target, %	9.30%
Total additional capacity required, %	11%
Absolute risk to convergence path requirement, €	3,857,903,915
Policy cost at risk, €	5,404,770,147

If convergence risk kicks in, €	-1,546,866,231
Emissions limit surplus equivalent, gCO_2/ km	4.2

Under the current regulatory limits in 2025, the transition risk amounts to a negative €0.4 billion. The figure is arrived at by finding the difference between the adjusted CAPEX gap and policy cost at risk. The transition risk considers financial gains in opportunity costs to the OEM by not investing more into the transition. I introduce a secondary measurement for the OEMs. After considering CAPEX and policy cost difference, the resultant financial surplus is translated into the equivalent emissions limit exceedance considering the financial gains from not investing in BEV manufacturing capacity.

The maximum policy risk builds on top of the minimum policy risk evaluation structure for OEMs to avoid fines. The following steps determine the extra CAPEX needed to reach the OEM's convergence pathway. The additional gap to the maximum policy risk boundary stands at €3.91 billion, which means OEMs will have to invest the stated sum in emitting at a below 2°C pathway.

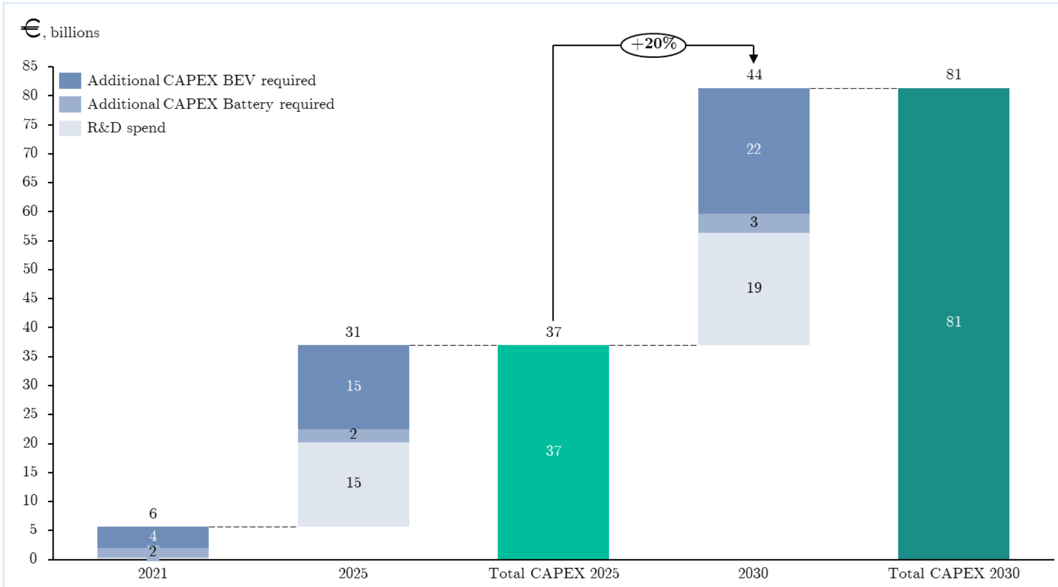
Additionally, I attempt to translate the opportunity cost gained into an emissions cost equivalent to OEMs. This metric translates the effective opportunity costs gained by not investing further into how much additional emissions limit is exceeded to represent its environmental impact. This insight is significant for institutional investors, OEMs, and policymakers, as they navigate the relationship between responsible stewardship, responsible business, and climate policymaking.

The subsequent sections will detail the CAPEX risk, policy risk, and model outcome analysis results.

5.2.1 CAPEX risk assessment

The CAPEX risk assessment forms part of the TEA model to determine the investment needed for an OEM to reach its climate commitment. *Figure 24* presents the baseline CAPEX requirement needed to reach climate commitment targets. In 2025, the total amount is close to €36.9 billion, compared to a €36.5 billion worth of capital commitment. The resultant differential capital expenditure is € 0.47 billion or 1.27% short to meet the commitment target. The current assessment also shows that a 20% increase in CAPEX allocation is needed, on top of the yearly CAPEX required to reach their 2030 target. This result is significant considering the compounded risk of falling short against the regulatory limits. The key assumption for the baseline scenario is a sector growth rate of 2%, no inflation risk, and the plant capacity to increase costs is linear due to modularity.

Figure 24: Waterfall chart showing additional CAPEX needed for R&D, battery, and BEV plant capacity building, split by the cumulative amount needed for periods between 2021, 2025, and 2030

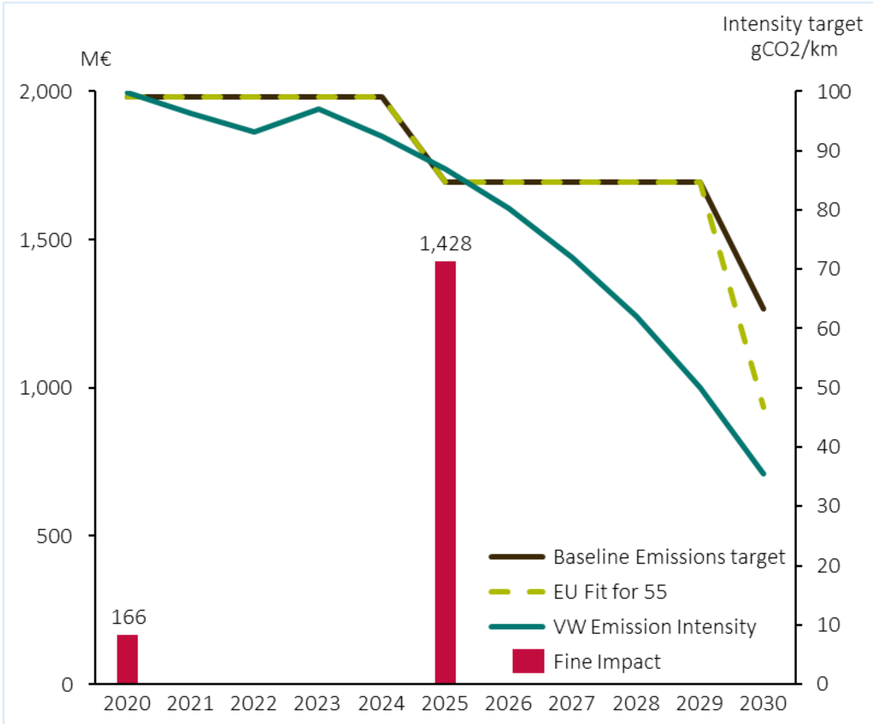


5.2.2 EU level policy risk assessment

VW has a 70% BEV sales target for the EU level climate target, operationalized as the end target. The production curve follows an exponential growth using an annualized compound growth rate with the climate target as the endpoint. But. the policy risk model considers the capacity shortfall as seen in the CAPEX risk assessment model. Therefore, an adjustment is made to the 2025 production target and 2030 target, assuming that the capacity risk is carried forward unless new information is introduced.

In the baseline analysis, the policy risk faced by VW amounts to € 1.6 billion from the studied 10-year regulatory exposure in the EU. This regulatory risk becomes intensified when the progressive regulatory limits kicks-in. *Figure 25* is used as a visualization aid in the communication process with stakeholders to demonstrate the policy risk present with VW's growth assumptions and climate target within the EU.

Figure 25: Baseline emissions limit and potential policy risks faced by VW in 2020-2030



5.2.3 Model outcome analysis

The transition risk model allows institutional investors to assess the ambitiousness of an OEMs climate strategy and validates that against physical climate data. One insight found is that institutional investors could go beyond assessing financial risk. The model's baseline scenario indicates that Volkswagen Group is running on adjusted fines amounting to ~0.5 billion € by missing regulatory targets and accounting for capital not invested, given the average fleet mass and volumes of cars sold in 2025. This model shows that the actual policy risk cost is less damaging than the expected €1.4 billion for institutional investors if only VW's financial risk return is assessed.

However, that is insufficient because this potential savings has two implications for institutional investors. First, they know that VW's reputational risk is at stake by missing the regulatory emissions target under public stakeholders' increasingly demanding climate performance. In other words, the reputational risks stemming from these savings could prove to be more damaging for VW Group. This finding provides an avenue for the institutional investors to table agenda in their engagement process with Volkswagen to clarify their climate strategy further. Second, they can use this information to validate against other OEMs and explore potential policy risks escalation by policymakers, considering that some OEMs could benefit from a potentially asymmetric policy utility distribution between the OEMs. For example, the current policy favors the Big 3 in Europe, which sells a heavier fleet of cars, is subjected to a looser intensity requirement (Mock, 2019).

5.2.3.1 *Cash flow risk for OEMs*

For corporations to transition, they need to "evolve" into a new entity that offers lower carbon value propositions. However, change causes uncertainty, bringing volatility to corporation valuation, reflected in the cash flow pattern. A firm-level cash flow pattern with high volatility can cause underinvestment feedback that reduces expected firm value (stock price) and thus reduces external investor funds (Scordis et al., 2008).

From the model, the OEM's transition risk assessed in 2025 amounts to ~€ 400 million in effective cash impact. The findings present a cash flow volatility to the OEM, given its unforeseen impact on its cash balance. This interruption could result in four adverse observations on a firm's performance in today's greening market. First, external under-investment could result in internal under-investment for prospects at the firm level due to insufficient liquidity (Scordis et al., 2008). Second, facing a heightened transition urgency and policy risk environment, "dirty" firms could also invite financial penalty (Krueger et al., 2020) for failing to invest in transition (Walenta, 2020), which could, in turn, be potentially harmful to a corporation's cash balance. Third, the firm will have to provide additional cash to meet its commitment, which compounds on top of the policy risks costs. Fourth, their reputation is potentially at stake, which could invite even more damage to cash flow (Kuo & Chang, 2021).

Ultimately, the finding points to additional risks the OEM face, therefore could have a downstream impact on the cash volatility and its corporate valuation and financial returns. Therefore, this information is significant, as the input will affect the investment decision-making process and could drive away capital allocation into less risky opportunities.

5.3 Model confidence building: robustness and, validation and verification

The earlier sections demonstrated the results from a working model that successfully defines transition risks from a financial angle. However, that is only part of the requirement for influencing a decision-making process. For the model to be useful, the decision-makers must derive confidence from using the model

For this research, building confidence is done in two ways. The first is to test the model rigorously to ensure robustness before delivery to the model users. The second is to gather qualitative feedback from the stakeholder groups on the intangible perceptions of model usefulness.

The research found that the model is robust following the validation and verification processes. The parameters are checked thoroughly in the model confidence-building process, and the model assumptions are challenged thoroughly. In addition, the model structure criticized by experts in the team and scenario analysis is built so that the model users are free to explore assumptions. Primarily, the research adopts the validation and verification techniques from (Forrester &

Senge, 1980; van der Spek et al., 2020).model is structurally sound and robust for this research.

5.3.1 Model structure verification

The model structure is verified through workshops conducted internally with the SI Research team, where experienced researcher confirms the model dynamics and the operationalized key output.

In the process, I had to justify the model structure by presenting the internal model relationship between the CAPEX and policy risk assessments to the participating experts. First, I presented them with visual aids on high-level model decompositions, and then the model was walked through in detail to review for potential errors and improvements.

Next, the model is then presented to the investment team, where the objective is to assess the integration potential of the operationalized transition risk output into the investment decision-making process. For that, separate workshops were conducted, and the process was repeated by presenting the visual aids on model structure and followed by a model walk-through to challenge key assumptions.

This process is iterative based on the model components presented in the earlier section. The model decomposition is always first confirmed before moving into the model structure for more comments.

5.3.2 Parametric and assumption validation

The summary assumptions present in the model are presented in section [FIX]. The input parameters are publicly available data obtained through regulatory and corporate reports and news sources. On top of that, the key assumptions on CAPEX risk estimations are validated and confirmed by the investor relations officer from VW, which is accessible for institutional investors. The input parameters are provided with sources and can be traced through the hyperlinks provided in the spreadsheet model, with descriptive and special remarks for contextual knowledge where applicable.

5.3.3 Scenario-based sensitivity analysis

Further, the model confidence is strengthened using a sensitivity test to show that the model should (or should not) work under various conditions.

For sensitivity analysis, I defined two key drivers: (i) gap to production and (ii) company growth rate as the main inputs to influence policy risk outcome. The ranges for the tested parameters are presented in *Table 6*. Apart from an OEM's company growth rate, other parameters such as scenarios setup, transition speed, and OEM carbon intensity are not examined for sensitivity in the model.

Table 6: Base case parameters for sensitivity test setup, base case growth rate is obtained from a market report using 2013-2017 5 years compounded annual growth rate and the gap to production target figure relies on CAPEX gap found

Tested drivers	Low	Base	High	Speculative
Company growth rate	-1%	2.00%	5%	x
Gap to Production Target	0%	-1.27%	-16%	2%

The tests also capture parameters within the CAPEX risk assessment as it relies on the growth rate. The resultant CAPEX gap to production measures how much production capacity gap is present, and when altered, covers the changes within the CAPEX risk assessment model itself. I designed 11 additional scenarios on top of the base case in the test by introducing random permutations. These scenarios are then tested against the three policy scenarios defined, see *Table 7*. I find three main observations from the sensitivity test against the parametric scenario setup:

1. Missing CAPEX has a significant impact on policy risk, and the sectoral growth rate has a relatively minor impact on the risk.
2. High growth scenarios will also increase policy risk as overall sales pour in.
3. Safest scenario (where fines = 0.17) ensures extra CAPEX is invested.

Table 7: Parametric tests against key policy scenarios defined in the model

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			Policy Scenarios		
Parametric Scenarios	**Company growth rate**	**Gap to production**	**EU Regulatory Baseline**	**EU "Fit for 55"**	**VW Convergence Risk**
			Policy risk, € billions		
1- Base Case	2%	-1%	1.59	1.59	36.40
2- Bad growth no gap	-1%	0%	0.83	0.83	19.80
3. High growth high gap	5%	-16%	160.75	164.81	231.03
4. Base growth no gap	2%	0%	0.94	0.94	23.40
5. High growth base gap	5%	-1%	1.82	1.82	43.89
6. Low growth high gap	-1%	-16%	102.17	104.42	148.15
7. High growth no gap	5%	0%	1.06	1.06	27.58

8. Low growth base gap	-1%	-1%	1.40	1.40	30.10
9. Base growth high gap	2%	-16%	128.49	131.53	185.43
10. Low growth + exceed	-1%	2%	0.17	0.17	11.49
11. Base growth + exceed	2%	2%	0.17	0.17	13.21
12. High growth + exceed	5%	2%	0.17	0.17	15.15

The full results of the sensitivity test are plotted in 3D surface charts for each scenario. The visualization is borrowed from the works of (van der Spek et al., 2020), where they used a similar chart for the parametric test. As a result, the chart is able to meaningfully show the full result of the tested parametric scenarios against policy scenarios, where the number of the parametric tests are shown following the order indicated in *Table 7*.

From the scenario analyses, I can summarize that scenarios with a high production gap (-0.16) tend to incur significant losses to VW, as they cannot reduce their fleet intensity without prior investments. However, the model also behaves expectedly, as the production result reflects whether they meet exceed regulatory threshold without further policy adjustments (see *Figure 26*, *Figure 27*, *Figure 28*.

Figure 26: 3D surface chart showing risk profiles with parametric scenarios tested against EU Regulatory baseline emission limits

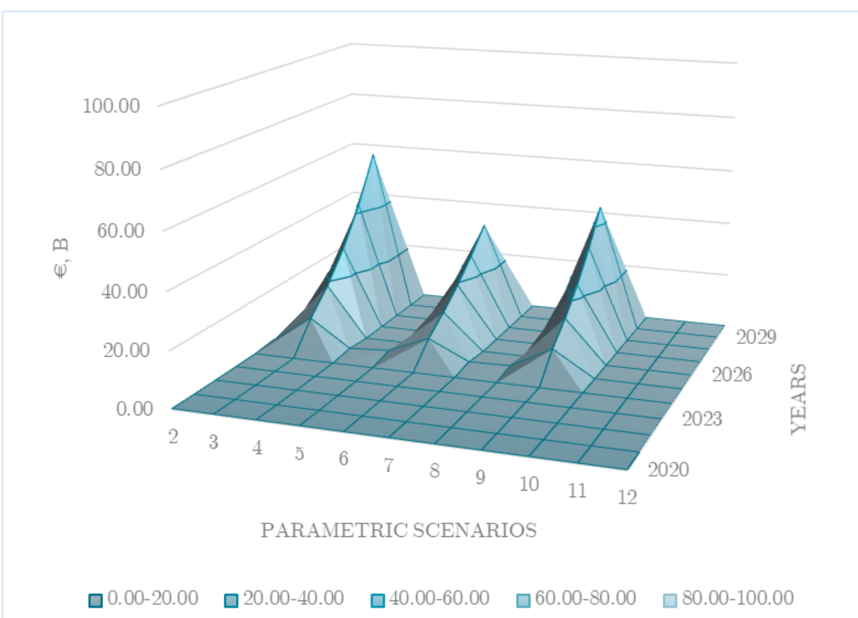


Figure 27: 3D surface chart showing risk profiles with parametric scenarios tested against EU "Fit for 55" emission limits

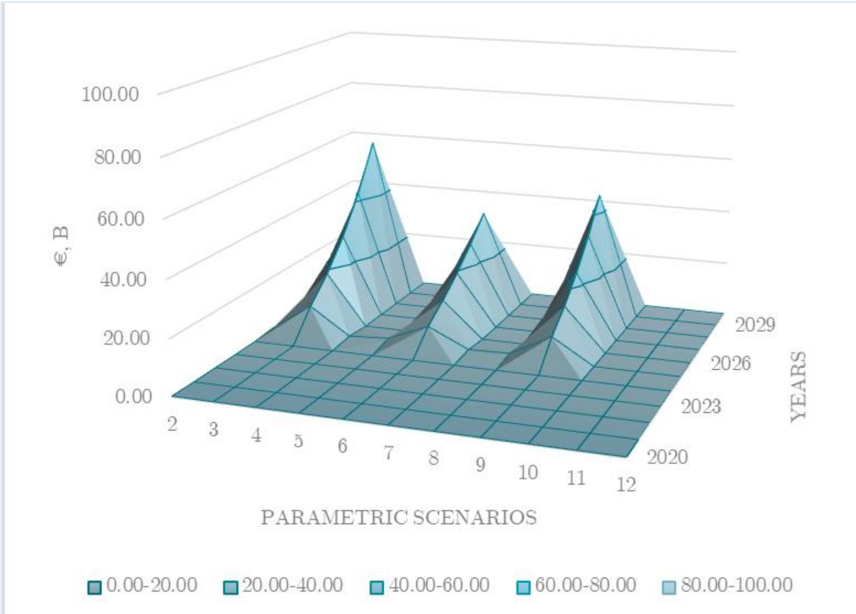
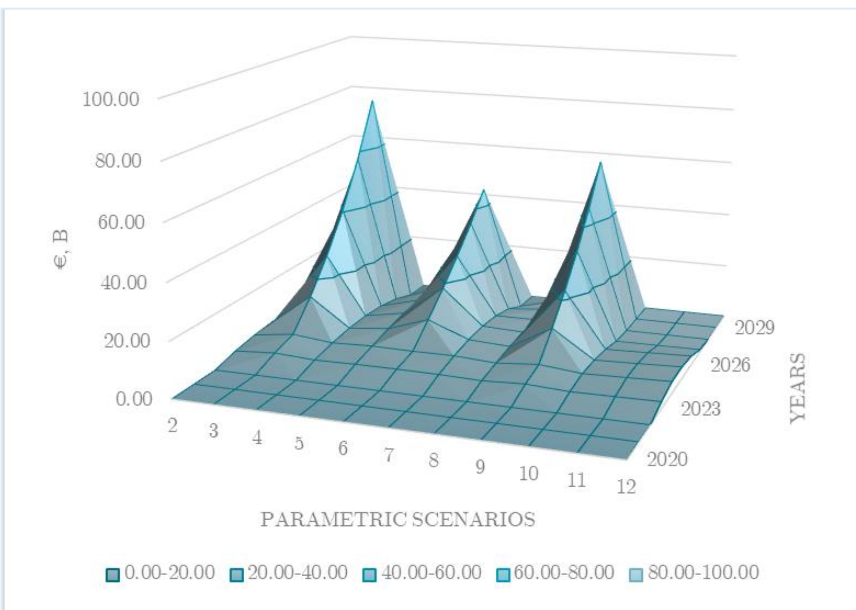


Figure 28: 3D surface chart showing risk profiles with parametric scenarios tested against VW convergence path emission limits



5.3.4 Extreme value test

The last test used to examine model sensitivity is an extreme value test. The extreme value test is helpful to test whether abnormal input will disrupt how the model behaves. The extreme value test uses a ±50% to alter the two key drivers in the sensitivity analysis. The test results show that the model behaves expectedly (see *Table 8*). An extremely high growth value with an extremely high gap to production (high gap means to exceed BEV production requirement) shows no regulatory risk post-2021. The same result is expected for extremely low growth but a high production gap. The other two scenarios show similar expectations, where low growth and low gap to production value show a small impact on fines due to volume influence. High growth with a low gap to production shows high fines, given that the OEM should shift to near full ICE production in the EU. However, this result is unrealistic as there is a production threshold that the manufacturers must meet before being subjected to the framework. Nevertheless, this result is acceptable since the objective is to test the model behavior under extreme inputs.

Table 8: Extreme value tests using permutation of 50% increment or decrement in both key drivers

	Test Setup			
Extreme Value Test	**Extreme Var High High**	**Extreme Var Low High**	**Extreme Var High Low**	**Extreme Var Low High**
Company growth rate	50%	-50%	50%	-50%
Gap to production	50%	-50%	-50%	50%
Year				
2020	0.17	0.17	0.17	0.17
2021	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00
2023	0.00	0.19	5.05	0.00
2024	0.00	0.07	5.81	0.00
2025	0.00	0.78	190.41	0.00
2026	0.00	0.71	520.17	0.00
2027	0.00	0.53	1,157.62	0.00
2028	0.00	0.36	2,343.56	0.00
2029	0.00	0.23	4,492.14	0.00
2030	0.00	0.01	592.95	0.00
Total policy cost, €	**0.17**	**3.05**	**9,307.86**	**0.17**

5.4 Semi-structured interview analysis

The semi-structured interview targets the stakeholder groups in the research with differing responsibilities in the organizations. The functions involved in this research are Investment Research, Sustainable Investing Research, and Active Ownership teams.

For each stakeholder group, I provide them with different questions that match their interest in the model. In the next section, I present a synthesis from the responses to answer the sub-research question 4. Below, I provide a recap of the questions asked by the expert stakeholders. Each sub-section provides the syntheses, split by team functions; direct quotes are in *"quotations"*.

5.4.1 Investment Research team

1. What do you think of the potential for financial risk integration using *the model?*

2. How do you think this model compares mutual exclusivity (overlap of measured risks in measurement methodology) to other climate risk indicators such as MSCI, GEVA, and RobecoSAM?
3. In terms of transition risk, is the exhaustiveness appropriate with the measured scope, i.e., committed capital risk and policy risk?
4. What do you think about the sensitivity analysis setup? Is it sufficient to build confidence?
5. What about speculative assumptions to test, i.e., increasing social costs, battery costs projection?

Feedback synthesis from the Investment Research team

The feedback gathered from the participating investing team member shows that the model has a high potential for transition risk assessment integration (see *Table 9*). The expert practitioners involved were satisfied with the model foundation, looking at the model structure, key assumptions, and further measures taken to assess the robustness of the model. In addition, the model presents a clear boundary of transition risk that is financial material specific for the auto sector and helps decision-makers to provide clear weightage towards transition risk. Finally, the model confidence built-in through validation and verification via sensitivity analysis, parametric tests, and assumptions were helpful and sufficient, especially since the tests were partially constructed with specific inputs.

Table 9: Feedback from the Investment Research team on the model outcome and confidence-building

Feedback area	**Investment Research** Financial risk and opportunity research: 3/ [43%]
Model outcome	▪ The **model studies material climate risks and impact faced by car companies** which is more useful than ESG reports/ ratings ▪ "Useful", **tangible output used as a direct input for investment valuation models** in credits and fundamental research ▪ **Allows for direct comparison between firms** in the auto sector ▪ "Their output should help us to determine the impact of climate (transition) risk on credit fundamentals." ▪ "The main difference is that this tool makes it so much more tangible. Most tools are fairly generic/broad, and the output of often difficult to translate into a tangible impact on the company. The other tools often provide a ranking, but again, as the output is difficult to interpret, it does not say that much." ▪ "Things like MSCI CVAR or Sustainalytics ESG risk rating will give a figure that is based on a broad range of factors, some of which you might not consider too relevant yourself" ▪ "It (the model) focuses on what is by far the most important climate aspect for the automotive sector."

Model confidence building	▪ Sensitivity analysis allows stakeholders to **test and challenge key assumptions** ▪ **Communicating assumptions helps with alignment** between stakeholders ▪ **The boundary is appropriate,** i.e., exclusion of lifecycle analysis (LCA), assumptions on technology costs, and climate targets ▪ "Yes, that is (the sensitivity test) useful. Primarily showing that (small) adjustments in assumptions do not result in large deviations in outcome increases confidence." ▪ "It (social costs) is very difficult to forecast. Battery costs are also very dependent on commodity prices, which are difficult to forecast, especially longer than one year out.

5.4.2 Sustainable Investing Research team

1. Compared to the previous work(s), what did you learn?
2. How will you change your approach to stakeholder communication in the future?
3. How will you build model confidence when communicating to other stakeholders?

Feedback synthesis from the Sustainable Investing Research team

The SI Research team are the ones I worked the closest with, given that the carbon performance tool is in research for other sectors. In addition, the TEA approach to assess transition risk is new to the team. In short, the research team found that the model structure is robust and can show connectedness from one part to another, which is a good start for techno-economic assessment application (see *Table 10*). They also indicated that the early stakeholder involvement with experts through participatory modeling from other teams is instrumental to gaining project alignment and interest throughout the process.

Additionally, they expressed that the current output is useful and novel because of a direct model "plug-in" possibility into existing financial models. Moreover, they stated that the co-creation process with other stakeholders was helpful and practical. Ultimately, the participatory modeling process reduced the friction in model communication towards the investment decision-making since the model provides a communications platform and the sensitivity analysis helps build user confidence.

Table 10: Feedback from the SI Research team on the model outcome and confidence-building

Feedback area	**SI Research** ESG (material) related issues research: 3/ [43%]
Model outcome	▪ **Elements within the model are more robust and interconnected** compared to other (previous) models ▪ A concrete case for a novel **climate risk research grounded in techno-economic assessment**

	▪ Scalable elements to **assess climate risk in other sectors** ▪ **The model generated interest in key stakeholders** because of stakeholder alignment and consistent involvement ▪ "The model produces tangible numbers to be used in financial models, which is very useful." ▪ "It is quantitative, but there are many assumptions to challenge, such as OEM sales mix target." ▪ "Future research could include the social cost on OEM performance, technological development." ▪ "However, the emission is not zero from an LCA perspective." ▪ "Compared to previous work on SDP for other sectors, I have to integrate more closely findings regarding decarbonization pathway and commitments to technology costs and possible policy implications. This time, the model was more robust, the findings of different deliverables were more interconnected, which made the outcomes of scenario analysis more realistic and meaningful." ▪ "In this project, we have learned how important it is to get clear feedback for stakeholders and always have in mind the objectives and needs of the users of the model/analysis. Therefore, in the future, I will involve stakeholders at an earlier stage, even just to inform them that the project has been kickstarted. Hopefully, this might increase participation and interest in the stakeholder group interest, which we failed to induce in some of our counterparts."
Model confidence building	▪ **Assumptions and boundaries communicated in advance** with stakeholders for structural alignment ▪ **Clear visuals and storytelling** help to onboard stakeholders on model usefulness ▪ **Validation and verification build user confidence** ▪ **Use concrete case studies as a starting point** for demonstration "When presenting your model to other stakeholders, a few things are essential to building confidence in the audience: • "State the boundaries and assumptions very clearly. Then, if possible, verify with them in advance the validity of such assumptions. This way, the conversation can start with everyone on the same page." • "Provide visuals to assist in the "storytelling" of what the data and the findings are saying." • "Backtest data (validation and verification), if possible. A good example is applying a policy cost model to determine VW's 2020 fines. Good to put results in perspective and identify the level of confidence that can be expected in the model." • "Choose meaningful examples for the audience that show how your work can be integrated into your stakeholders' daily work."

Active Ownership team

1. How will this tool assist your engagement activities with car companies?
2. How does the outcome of this tool compare to other climate risks assessment tools, i.e., ESG ratings?

3. How should the model build confidence in order to be useful?

The engagement team is responsible for communicating with the corporations to exercise institutional investors' stewarding responsibility (Novick et al., 2018). The feedback indicated that the input is tangible to set up the conversation with corporations and helps to complement the current qualitative, thematic engagement materials (see *Table 11*). In addition, the output could be useful for the engagement team to compare across companies for a further level of prioritization from a transition risk angle. Finally, on model confidence building, they perceive that the trust built through working with the current SI team helps them understand the usefulness of outputs. One caveat, though, the model and data assumptions should be communicated clearly to the team.

Table 11: Feedback from the Active Ownership team on the model outcome and confidence-building

Feedback area	**Active Ownership** Engagement, voting, and agenda-setting: 1/ [14%]
Model outcome	▪ **Tangible input for granular climate strategy engagement**/ agenda setting ▪ Helps with substantiating/ **prioritizing companies to engage** ▪ **Complements current qualitative engagement** content, but this number is not as important ▪ Put to **discussion on reputational risk now possible** ▪ Supports peer comparison to **track carbon performance**
Model confidence building	▪ **Trust in modelers' ability** is important ▪ **Transparency and communication of stated data assumptions and limitations** are important

5.5 Question for every modeler: is the model useful?

The feedback and interest gathered from other teams show that the model is indeed useful. Significantly, the targeted approach of operationalizing relevant transition risk into a cash flow issue offers a direct path to include transition risk in the decision-making process as part of the United Nations Principle for Responsible Investing's (UNPRI) suggested framework. Moreover, in my opinion, this assessment framework shifts away from a "black-box" nature of ESG ratings, where the scoring methodologies can be obscure, difficult to be understood by users, and subjective to assess quality (Berg et al., 2019; Boffo & Patalano, 2020).

Interestingly, some stakeholders have already invited the model outcome into their analysis, where transition risk is part of their decision-making process. The invitation shows an early promise of investment decision-making integration potential. From a decision-process flow angle, I imagine now the model serves as an additional, quantifiable, but integral metric to the currently used financial models based on a common asset valuation framework (Damodaran, 2012).

6 Concluding remarks, reflections, and future work

The chapter concludes the endeavor undertaken with a results synthesis to answer the main research question:

"How can institutional investors study transition risk in the forms of capital requirement and regulatory fines in the auto sector?"

Presented next is a reflection on the societal relevance of this proposed model, considering the research implications for the three societal actors involved-institutional investors, corporations, and policymakers. Third, a reflection shows appreciation towards the participatory modeling process; its added value in bringing diverse and multidisciplinary stakeholders together is unmissable.

6.1 Significance of the transition risk assessment

The expert practitioners' consensus pointed to promising continuation in the model application, development, and expansion within institutional investing. Furthermore, the qualitative feedback indicated that the model constructed is useful for institutional investors to assess firm-level transition risk in the auto sector. With the added value of a participatory modeling process, the model captures the financially relevant transition risk factors from capital requirement and regulatory angles and has effectively assessed transition risk for institutional investors and passenger car auto manufacturers.

From a higher-level point of view, the model framework paves the way for a transparent, evidence-based to assess transition risk as part of the climate investment decision-making process for internal and external stakeholder arbitrations in the field of institutional investing. However, more importantly, the framework presents an alternative to the less ideal ESG assessment frameworks. Moreover, the participatory modeling process with the expert stakeholder groups of diverse knowledge capacity is effective and thus recommended for similar future settings.

6.2 Societal relevance and policy reflection

This section reflects on what it means to define "utility gains" on a local and global scale. And finally, it reflects on the aptness of the participatory modeling process in an increasingly multidisciplinary solution space.

6.2.1 Climate policy in the EU

Given the policy implication from the EU, the reflection starts with first a European Lens and shifts towards global implications. The transition risk assessment model considers the climate actions by corporations and policymakers on top of their own financial stewardship needs.

In doing so, the asset manager inadvertently will have to be put in the shoes of both the firm and policymaker to assess the best move of interest. However, this interest must be carefully defined as pure financial gains. Although it serves their short-term interest, even in the face of climate transition, it would probably cause a reduction in long-term gains considering the aggregated feedback into more significant physical risks. The model outcome shows that the OEM is motivated to transition by avoiding financial penalties and potential reputational risks.

Sometimes, corporations resort to lobbying efforts, creating multi-issue games for policymakers to bargain for a perceived less harsh transition. However, despite the increasing momentum for climate policy, the current pathway still leaves room for an implied temperature rise beyond 1.5°C. As such, the European policymakers must resolve to set the appropriate climate targets and induce comprehensive, evidence-led transition frameworks. The current target seems already achievable for OEMs within the EU. For sure, this assessment framework is also applicable for policymakers to assess risk levels faced by corporations in various sectors to determine policy pricing. Since, it seems that utility gains could drive the moves that an OEM will take.

6.2.2 Climate policy beyond the EU

With the EU policy in place, the evidence shows that the private actors will prioritize regions impacted by policy actions. However, sadly, the policy review informs us that other countries' policy implementation and enforcement are still yet to take off (save for China, which operates with a different policy framework). This observation tells us that the climate policies beyond Europe have even more work to do before even considering influencing private actors in those regions.

Understandably, the governance efficacy in developing regions is less than ideal. However, this leaves room for corporate actors and institutional investors to influence corporate agendas. There is the concept of global governance, where corporations deploy global best practices to ensure the same way of working no matter the region, as evident in health and safety operations (Lin-Hi & Blumberg, 2011). Shouldn't this idea of global governance be implemented the same for environmental practices? Is it time to work with local governments to speed up the transition for global OEMs?

I would argue that this would provide an edge for private actors, for example, the OEMs, as it could increase consumer confidence in the brand, ensure a social license to operate, and increase the positive influence of private actors in transition policymaking (Giglio et al., 2020; Pianta et al., 2021). Furthermore, perhaps for institutional investors with a vision of climate risks, there is indeed room for at least transition risk to be formalized globally into regulations. But, again, the implication is a globalized transition risk priced in for corporations and institutional investors alike.

6.2.3 Merging physical sciences and finance through co-creation

Participatory modeling brought a sense of ownership for the stakeholders involved, given its inherent process of inclusion in its process. As the world shifts and systems interconnectedness are better appreciated, multidisciplinary settings are inevitable in the future of work. The participatory modeling process forced the modeler to step into the shoes of various stakeholders to understand the respective decision-making processes and design the model to meet interests on multiple fronts. Using the techno-economic model allowed the traditionally financially centric expert stakeholders to understand how technology and policy can fundamentally influence the behavior of corporations. With the techno-economic assessment model, institutional investors with aggressive climate strategies can move to table shareholder agendas in their portfolio companies. This action helps institutional investors to exact change by supplementing the agenda with data-driven evidence, as seen through the moves of Engine No. 1 in replacing Exxon Mobil board seats. (Christie, 2021)

Ultimately, the participatory modeling process with a techno-economic model provides a novel way of assessing transition risk in the auto sector. Participatory modeling first allowed deliberation to challenge common assumptions about the auto sector's transition risk conceptualization. Then, on the back of the deliberation process, the participatory modeling promoted a strong sense of alignment between the stakeholders involved on decision assumptions. Furthermore, there were only a few frictions throughout the modeling process because of the buy-ins provided by the expert stakeholders through the participatory modeling process. Nonetheless, the model should still be robust by introducing sufficient confidence-building measures to ensure that the model functions as intended.

6.3 Research limitations

As with all academic pursuits, limitations exist and flaws within the research boundary. I have been steadfast in ensuring the best available approaches to ensure a rigorous academic output throughout the process. Here I address the shortcomings present in the research and lay bare the flaws for intellectual scrutiny.

Research scoping

On research scoping, the auto-sector is a fortunate sector, as there are already BEV companies such as Tesla that guide incumbents' transition. Therefore, the critical assumption of technological and policy maturity is sound. However, much more work is needed to assess their technological development and deployment cycle before going into transition risk for other hard-to-abate sectors such as steel, cement, and fossil fuel. In order words, other sectors face different forms of financial material risks that are yet to be categorized. Quite significantly, although in line with the EC’s assessment framework, the lifecycle assessment for the auto sector is not accounted for, where mining presents significant emissions (Gebler et al., 2019).

Additionally, the only OEM presented in this research is Volkswagen, which misses out on the opportunity for a comparative study. With an addition of a comparative study, the analysis of the results would have been more informative, and the same applies to participant feedback. Indeed, that is the plan moving forward for the research project within the organization.

Techno-economic assessment model

On the techno-economic assessment model itself, a few flaws could be addressed better still to improve its usefulness further. First off, the model is hard to scale as it approaches transition risk from a fundamental or bottom-up approach. That means the data points are not represented in empirics and will have to be collected either from a database (if available) or manually through Google. Parallelly, no common standardized database for climate targets is available despite a proliferation in data disclosure. As a result, this tremendously reduces the potential for an automated assessment flow with computer languages such as Python or R. Second, the model is novel. That means there is no way to cross-reference it against pre-existing models. For that, I studied techno-economic models from various actors to understand the requirements of building one. Third, the model is done in a spreadsheet, which means while the model could be very interactive, it is hard to debug unless you are the modeler, and it is prone to user influence on model dynamics which could lead to errors. Fourth, a detailed model manual is submitted for the team to maintain the model upon delivery to improve the model clarity. On top of that, the model flow is first charted and then analyzed using the ExploreXL software for verification.

On the model data, admittedly, a statistical approach used to treat the model parameters would have garnered much higher confidence in the model output, where the confidence intervals could be generated as a quantitative indicator.

Participatory modeling

On the use of participatory modeling, it must be expressed that the participatory modeling framework is not fully informed to all stakeholders in participation. However, it was instead integrated into the research project management process. Additionally, although the stakeholder group is diverse, the participants are nonetheless still situated within the same industry, and therefore groupthink bias exists. For that reason, the feedback interview is conducted on a 1-1 basis. To counteract that, perhaps interviewing sector experts from non-financial fields, such as the ICCT in the public policy research field, would have yielded additional dimensions to insights generation. Not all the stakeholders were present at once throughout the workshops conducted due to scheduling conflicts. Indeed, this weakens the causality that the participatory modeling process strengthens the techno-economic assessment model building process. However, it must be mentioned that the participatory model helped tremendously with gaining alignment from the diverse stakeholder group involved.

6.3.1 Future work

Indeed, there is an integration potential of including transition risk into the investment decision-making process. The research conducted is still a new approach, and therefore expected to be subject to much rigorous scrutiny in the finance and climate sciences fields. The subsequent writings recommend future research for institutional investors, researchers, and policymakers.

First, the transition risk could be embedded further into the investment decision-making process by deriving a bottom-up transition risk beta assessment that could be used empirically across portfolios. The bottom-up derived empirics is especially interesting because of the rising quantitative funds in the industry, as they struggle to incorporate data from a bottom-up approach and usually rely on empirical signals such as portfolio level intensity, which is backward-looking into historical emissions.

Second, the participatory modeling process could be repeated in combination with the same assessment framework but with a different group of participants to test the influence of the framework and the modeling process. Perhaps, the model structure might even experience change, given the co-creation factor and thus stakeholder input heavily influence the model structure.

Third, policymakers could incorporate the transition risk assessment framework to standardize data disclosure so that industry practitioners can operationalize the data to understand transition risk further. The research results show that the corporations have yet to meet their convergence pathways even below 2°C. The assessment framework should provide policymakers with a grounded approach to set better OEM targets by considering capital risk.

Lastly, the sensitivity test can be expanded further to include more robust uncertainty studies as the research project expands. Regrettably, there are only 12 scenarios tested in the research, which is quite limited compared to the available techniques in the present day, which could have yielded far more insights. Therefore, subjecting the model to deep uncertainty, for example, through an Exploratory Modeling and Analysis workbench (EMA) to determine parametric ranges and scenario exploration (Kwakkel, 2017), could be a good idea moving forward once the model assessment framework is tested to be consistent.

References

Adams, W. C. (2015). *Conducting Semi-Structured Interviews*. John W.

Alarfaj, A. F., Griffin, W. M., & Samaras, C. (2020). Decarbonizing US passenger vehicle transport under electrification and automation uncertainty has a travel budget. *Environmental Research Letters*, *15*(9). https://doi.org/10.1088/1748-9326/ab7c89

Ansolabehere, S. (2004). Part 7 : Systems of Equations. *Notes*.

Anson, M. (2012). Asset owners versus asset managers: Agency costs and asymmetries of information in alternative assets. *Journal of Portfolio Management*, *38*(3), 89–103. https://doi.org/10.3905/jpm.2012.38.3.089

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research*, *253*(1), 1–13. https://doi.org/10.1016/j.ejor.2015.12.023

Bachner, G., Mayer, J., Steininger, K. W., Anger-Kraavi, A., Smith, A., & Barker, T. S. (2020). Uncertainties in macroeconomic assessments of low-carbon transition pathways - The case of the European iron and steel industry. *Ecological Economics*, *172*(April 2019), 106631. https://doi.org/10.1016/j.ecolecon.2020.106631

Baer, H. A. (2012). Global capitalism and climate change. *Handbook on International Political Economy*, 395–414. https://doi.org/10.1142/9789814366984_0023

Basaglia, P., Carattini, S., Dechezleprêtre, A., & Kruse, T. (2020). *Climate policy uncertainty and firms ' and investors ' behavior ▯ Extended abstract*. 1–8.

Belsom, T., Wearmouth, C., Chatterjee, S., & Baker, E. (2019). Climate change for asset owners. *Principles for Responsible Investment*, *June*, 1–10. https://www.unpri.org/download?ac=10843

Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., & Mierlo, J. Van. (2017). Cost projection of state of the art lithium-ion batteries for electric vehicles up to 2030. *Energies*, *10*(9). https://doi.org/10.3390/en10091314

Berg, F., Kölbel, J., & Rigobon, R. (2019). Aggregate Confusion: The Divergence of ESG Ratings. *SSRN Electronic Journal*, 0–63. https://doi.org/10.2139/ssrn.3438533

Bernanke, B. S. (1983). Irreversibility, uncertainty, and cyclical investment. *Quarterly Journal of Economics*, *98*(1), 85–106. https://doi.org/10.2307/1885568

Black Rock. (2020). *ESG Integration Insights*.

BlackRock. (2020). *Sustainability as BlackRock's New Standard for Investing*. 1–11. https://www.blackrock.com/corporate/investor-relations/blackrock-client-letter

Boffo, R., & Patalano, R. (2020). ESG Investing Practices, Progress Challenges. *OECD*

Paris, 88. www.oecd.org/finance/ESG-Investing-Practices-Progress-and-Challenges.pdf%0AThis

Brav, A., Jiang, W., & Kim, H. (2015). The Real Effects of Hedge Fund Activism: Productivity, Asset Allocation, and Labor Outcomes. *Review of Financial Studies*, *28*(10), 2723–2769. https://doi.org/10.1093/rfs/hhv037

Brav, A., Jiang, W., Ma, S., & Tian, X. (2018). How does hedge fund activism reshape corporate innovation? *Journal of Financial Economics*, *130*(2), 237–264. https://doi.org/10.1016/j.jfineco.2018.06.012

Brav, A., Jiang, W., Partnoy, F., & Thomas, R. (2008). Hedge fund activism, corporate governance, and firm performance. *Journal of Finance*, *63*(4), 1729–1775. https://doi.org/10.1111/j.1540-6261.2008.01373.x

Bruno, G., Esakia, M., & Goltz, F. (2021). *"Honey, I Shrunk the ESG Alpha": Risk-Adjusting ESG Portfolio Returns*. *April*. https://cdn.ihsmarkit.com/www/pdf/0521/Honey-I-Shrunk-the-ESG-Alpha.pdf

Bubeck, S., Tomaschek, J., & Fahl, U. (2016). Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. *Transport Policy*, *50*(2016), 63–77. https://doi.org/10.1016/j.tranpol.2016.05.012

Buchbinder, M., Blue, C., Juengst, E., Brinkley-Rubinstein, L., Rennie, S., & Rosen, D. L. (2020). Expert stakeholders' perspectives on a Data-to-Care strategy for improving care among HIV-positive individuals incarcerated in jails. *AIDS Care - Psychological and Socio-Medical Aspects of AIDS/HIV*, *32*(9), 1155–1161. https://doi.org/10.1080/09540121.2020.1737641

Carney, M. (2015). Breaking the tragedy of the horizon - climate change and financial stability - speech by Mark Carney | Bank of England. *Bank of England*, *September*, 1–16. https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability

Cheema-Fox, A., Laperla, B. R., Serafeim, G., Turkington, D., & Wang, H. (2019). Decarbonization Factors. *SSRN Electronic Journal*.

Christie, A. L. (2021). *The Agency Costs of Sustainable Capitalism* (Issue 7). http://www.law.cam.ac.uk/ssrn/

Christie, A. L., & Christie, A. (n.d.). *The Agency Costs of Sustainable Capitalism*. Retrieved May 11, 2021, from http://www.law.cam.ac.uk/ssrn/

Ciscar, J. C., Iglesias, A., Feyen, L., Szabó, L., Van Regemorter, D., Amelung, B., Nicholls, R., Watkiss, P., Christensen, O. B., Dankers, R., Garrote, L., Goodess, C. M., Hunt, A., Moreno, A., Richards, J., & Soria, A. (2011). Physical and economic consequences of climate change in Europe. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(7), 2678–2683. https://doi.org/10.1073/pnas.1011612108

Cox, B., Bauer, C., Mendoza Beltran, A., van Vuuren, D. P., & Mutel, C. L. (2020). Life cycle environmental and cost comparison of current and future passenger cars under different energy scenarios. *Applied Energy*, *269*, 115021.

https://doi.org/10.1016/J.APENERGY.2020.115021

Damodaran, A. (2012). *Investment valuation: Tools and techniques for determining the value of any asset* (Vol. 666). John Wiley & Sons.

Demers, E., Hendrikse, J., Joos, P., & Lev, B. (2021). *ESG Didn't Immunize Stocks During the COVID-19 Crisis, But Investments in Intangible Assets Did*.

Dietz, S., Bienkowska, B., Gardiner, D., Hastreiter, N., Jahn, V., Komar, V., Scheer, A., & Sullivan, R. (2021). *TPI State of Transition Report 2021 Pathway Initiative*. 1–44. https://www.transitionpathwayinitiative.org/publications/82.pdf?type=Publication

Dimson, E., Karakas, O., & Li, X. (2012). Active Ownership. *SSRN Electronic Journal*, *Li*. https://doi.org/10.2139/ssrn.2154724

Eccles, R. G., Ioannou, I., & Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. *Management Science*, *60*(11), 2835–2857. https://doi.org/10.1287/mnsc.2014.1984

Edgecliffe-Johnson, A., & Mundy, S. (2021). *Big business and COP26: are the 'net zero' plans credible?* 1–11.

Edmans, A. (2021). *Grow the Pie: How Great Companies Deliver Both Purpose and Profit*. Cambridge University Press. https://books.google.nl/books?id=Oq5xzgEACAAJ

Ellsberg, D. (1961). Risk , Ambiguity , and the Savage Axioms. *The Quarterly Journal of Economcis*, *75*(4), 643–669.

Emmett, R. (2020). Reconsidering Frank Knight's Risk, Uncertainty, and Profit. *Independent Review*, *24*(4), 533.

European Commission. (2021). *REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition*.

European Parliament. (2019). The European Parliament declares climate emergency. *European Parliament*, 1–3. https://www.europarl.europa.eu/news/en/press-room/20191121IPR67110/the-european-parliament-declares-climate-emergency

Foerster, A. (2014). The asymmetric effects of uncertainty. *Economic Review*, *3*, 5–26. https://m.kansascityfed.com/publicat/econrev/pdf/14q3Foerster.pdf

Fontaras, G., Ciuffo, B., Zacharof, N., Tsiakmakis, S., Marotta, A., Pavlovic, J., & Anagnostopoulos, K. (2017). ScienceDirect ScienceDirect The difference between reported and real-world CO 2 emissions: How much improvement can be expected by WLTP introduction? *-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY. ScienceDirect The difference between reported and real-world CO 2 emissions: How much improvement can be expected by WLTP introduction? *-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY. *Transportation Research Procedia*, *25*, 0–000. https://doi.org/10.1016/j.trpro.2017.05.333

Forrester, J. W., & Senge, P. M. (1980). Tests for building confidence in system dynamics models. In *TIMS Studies in the Management Sciences* (Vol. 14, Issue 1, pp. 209–228).

Fried, S., Novan, K., & Peterman, W. B. (2021). The Macro Effects of Climate Policy Uncertainty. *Federal Reserve Bank of San Francisco, Working Paper Series*, 1–50. https://doi.org/10.24148/wp2021-06

Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance and Investment*, *5*(4), 210–233. https://doi.org/10.1080/20430795.2015.1118917

Fulton, L., Lah, O., & Cuenot, F. (2013). Transport pathways for light duty vehicles: Towards a 2° scenario. *Sustainability (Switzerland)*, *5*(5), 1863–1874. https://doi.org/10.3390/SU5051863

Galvin, R. (2021). Can President Biden decarbonize the United States light vehicle fleet? Social-technical compromise scenarios for five automakers. *Energy Research and Social Science*, *77*(May), 102104. https://doi.org/10.1016/j.erss.2021.102104

Gavriilidis, K. (2021). Measuring Climate Policy Uncertainty. *SSRN Electronic Journal*, 1–9. https://doi.org/10.2139/ssrn.3847388

Gebler, M., Cerdas, F., Kaluza, A., Meininghaus, R., & Herrmann, C. (2019). Integrating Life-Cycle Assessment into Automotive Manufacturing—A Review-Based Framework to Measure the Ecological Performance of Production Technologies. *Sustainable Production, Life Cycle Engineering and Management*, 45–55. https://doi.org/10.1007/978-3-319-92237-9_6

Gebler, M., Cerdas, J. F., Thiede, S., & Herrmann, C. (2020). Life cycle assessment of an automotive factory: Identifying challenges for the decarbonization of automotive production – A case study. *Journal of Cleaner Production*, *270*, 122330. https://doi.org/10.1016/J.JCLEPRO.2020.122330

Gehman, J., Lefsrud, L. M., & Fast, S. (2017). Social license to operate: Legitimacy by another name? In *Canadian Public Administration* (Vol. 60, Issue 2, pp. 293–317). https://doi.org/10.1111/capa.12218

GFANZ. (2021). *COP26 and The Glasgow Financial Alliance for Net Zero (GFANZ)*.

Giglio, S., Kelly, B., & Stroebel, J. (2020). Climate finance. *Review of Financial Studies*, *33*(3), 1011–1023. https://doi.org/10.1093/rfs/hhz146

Hansson, S. O. (2013). *The ethics of risk: Ethical analysis in an uncertain world*. https://doi.org/10.1057/9781137333650

Harrison, G. W., & Ross, D. (2017). The empirical adequacy of cumulative prospect theory and its implications for normative assessment. *Journal of Economic*

Methodology, *24*(2), 150–165. https://doi.org/10.1080/1350178X.2017.1309753

Hirshleifer, A. J. (1965). Investment Decision Under Uncertainty: Choice-Theoretic Approaches. *The Quarterly Journal of Economcis*, *79*(4), 509–536.

Hong, H., Karolyi, G. A., & Scheinkman, J. A. (2020). Climate finance. *Review of Financial Studies*, *33*(3), 1011–1023. https://doi.org/10.1093/rfs/hhz146

IEA. (2020a). Energy Technology Perspectives 2020. In *Energy Technology Perspectives 2020*. https://doi.org/10.1787/ab43a9a5-en

IEA. (2020b). Trends in Electric Mobility. *Global EV Outlook 2020: Technology Report*, 39–85.

IEA. (2021). *Global EV Policy Explorer*.

Incropera, F. P. (2015). *Climate Change: A Wicked Problem: Complexity and Uncertainty at the Intersection of Science, Economics, Politics, and Human Behavior*. Cambridge University Press. https://doi.org/10.1017/CBO9781316266274

International Energy Agency. (2007). Climate policy uncertainty and investment risk. *Climate Policy Uncertainty and Investment Risk*, *9789264030*, 1–142. https://doi.org/10.1787/9789264030152-en

IPCC. (2021). IPCC 2021 Technical report. *Ipcc*, *August*, 150. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_TS.pdf

Jaques, E. (2008). Paying it forward. *Sustainable Business*, *146*, 32–33.

Jochem, P., Gómez Vilchez, J. J., Ensslen, A., Schäuble, J., & Fichtner, W. (2018). Methods for forecasting the market penetration of electric drivetrains in the passenger car market. *Transport Reviews*, *38*(3), 322–348. https://doi.org/10.1080/01441647.2017.1326538

Johnson, S. (2021). *ESG outperformance narrative "is flawed", new research shows*. 7–13.

Kahneman, D., & Tversky, A. (1967). Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, *47*(March), 263–292.

Kang, K., Seo, Y., Chang, D., Kang, S. G., & Huh, C. (2015). Estimation of CO2 transport costs in South Korea using a techno-economic model. *Energies*, *8*(3), 2176–2196. https://doi.org/10.3390/en8032176

Khan, M., Serafeim, G., & Yoon, A. (2016). Corporate sustainability: First evidence on materiality. In *Accounting Review* (Vol. 91, Issue 6, pp. 1697–1724). American Accounting Association. https://doi.org/10.2308/accr-51383

Knight, F. H. (1921). Risk Uncertainty and Profit Knight. In *Quarterly Journal of Economics* (Vol. 36, Issue 4, p. 682). http://www.jstor.org/stable/1884757?origin=crossref

König, A., Nicoletti, L., Schröder, D., Wolff, S., Waclaw, A., & Lienkamp, M. (2021). An overview of parameter and cost for battery electric vehicles. *World Electric Vehicle Journal*, *12*(1), 1–29. https://doi.org/10.3390/wevj12010021

Krueger, P., Sautner, Z., & Starks, L. T. (2020). The importance of climate risks for institutional investors. *Review of Financial Studies*, *33*(3), 1067–1111. https://doi.org/10.1093/rfs/hhz137

Kuo, L., & Chang, B. G. (2021). Ambitious corporate climate action: Impacts of science-based target and internal carbon pricing on carbon management reputation-Evidence from Japan. *Sustainable Production and Consumption*, *27*, 1830–1840. https://doi.org/10.1016/j.spc.2021.04.025

Kwakkel, J. H. (2017). *The Exploratory Modeling Workbench: An open source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making*. https://doi.org/10.1016/j.envsoft.2017.06.054

Lee, T. M., Markowitz, E. M., Howe, P. D., Ko, C. Y., & Leiserowitz, A. A. (2015). Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change*, *5*(11), 1014–1020. https://doi.org/10.1038/nclimate2728

Levin, J. (2006). *Choice under uncertainty* (pp. 1–34). https://doi.org/10.1016/0377-2217(89)90259-2

Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2012). Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sciences*, *45*(2), 123–152. https://doi.org/10.1007/s11077-012-9151-0

Li, F., & Polychronopoulos, A. (2020). *What a difference an ESG ratings provider makes, Research Affiliates Publication*. https://www.researchaffiliates.com/documents/770-what-a-difference-an-esg-ratings-provider-makes.pdf

Lin-Hi, N., & Blumberg, I. (2011). The relationship between corporate governance, global governance, and sustainable profits: Lessons learned from BP. *Corporate Governance*, *11*(5), 571–584. https://doi.org/10.1108/14720701111176984

Magnan, A. K., Pörtner, H. O., Duvat, V. K. E., Garschagen, M., Guinder, V. A., Zommers, Z., Hoegh-Guldberg, O., & Gattuso, J. P. (2021). Estimating the global risk of anthropogenic climate change. *Nature Climate Change*, *11*(10), 879–885. https://doi.org/10.1038/s41558-021-01156-w

Magnani, G., & Zucchella, A. (2018). Uncertainty in Entrepreneurship and Management Studies: A Systematic Literature Review. *International Journal of Business and Management*, *13*(3), 98. https://doi.org/10.5539/ijbm.v13n3p98

Maier, H. R., Guillaume, J. H. A., van Delden, H., Riddell, G. A., Haasnoot, M., & Kwakkel, J. H. (2016). An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environmental Modelling and Software*, *81*, 154–164. https://doi.org/10.1016/j.envsoft.2016.03.014

Malkiel, B. G. (1989). Efficient Market Hypothesis. In J. Eatwell, M. Milgate, & P.

Newman (Eds.), *Finance* (pp. 127–134). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-20213-3_13

McNulty, T., & Nordberg, D. (2016). Ownership, Activism and Engagement: Institutional Investors as Active Owners. In *Corporate Governance: An International Review* (Vol. 24, Issue 3, pp. 346–358). https://doi.org/10.1111/corg.12143

Meadowcroft, J. (2016). Let's get this transition moving! *Canadian Public Policy*, *42*(1), S10–S17. https://doi.org/10.3138/cpp.2015-028

Meckling, J., Sterner, T., & Wagner, G. (2017). Policy sequencing toward decarbonization. *Nature Energy*, *2*(12), 918–922. https://doi.org/10.1038/s41560-017-0025-8

Mercereau, B., Neveux, G., Sertã, J. P. C. C., Marechal, B., & Tonolo, G. (2020). Fighting climate change as a global equity investor. *Journal of Asset Management*, *21*(1), 70–83. https://doi.org/10.1057/s41260-020-00150-9

Mima, S., & Strolyarova, E. (2018). Cop21 Ripples. *Pathways*. https://www.cop21ripples.eu/wp-content/uploads/2018/07/RIPPLES-D2.4-Final.pdf

Mock, P. (2019). *CO2 Emission Standards for Passenger Cars and Light-Commercial Vehicles in the European Union*. *January 2019*. https://theicct.org/sites/default/files/publications/EU-LCV-CO2-2030_ICCTupdate_20190123.pdf

Monasterolo, I., Zheng, J. I., & Battiston, S. (2018). Climate Transition Risk and Development Finance: A Carbon Risk Assessment of China's Overseas Energy Portfolios. In *China and World Economy* (Vol. 26, Issue 6, pp. 116–142). https://doi.org/10.1111/cwe.12264

Nordhaus, B. W. D. (1977). *Economic Growth and Climate : The Carbon Dioxide Problem Author (s): William D . Nordhaus Proceedings of the Eighty-ninth Annual Meeting of the American Economic Assocation Published by : American Economic Association Stable URL : https://www.jstor.org/*. *67*(1), 341–346.

Novick, B., Edkins, M., & Clark, T. (2018). The Investment Stewardship Ecosystem. *Harvard Law School Forum on Corporate Governance*, *8*, 1–5. https://corpgov.law.harvard.edu/2018/02/12/ceo-tenure-rates/

Offer, G. J., Contestabile, M., Howey, D. A., Clague, R., & Brandon, N. P. (2011). Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK. *Energy Policy*, *39*(4), 1939–1950. https://doi.org/10.1016/j.enpol.2011.01.006

Page, S. E. (2006). Path dependence. *Quarterly Journal of Political Science*, *1*(1), 87–115. https://doi.org/10.1561/100.00000006

Papadis, E., & Tsatsaronis, G. (2020). Challenges in the decarbonization of the energy sector. *Energy*, *205*, 118025. https://doi.org/10.1016/J.ENERGY.2020.118025

Pianta, S., Brutschin, E., van Ruijven, B., & Bosetti, V. (2021). Faster or slower decarbonization? Policymaker and stakeholder expectations on the effect of the COVID-19 pandemic on the global energy transition. *Energy Research and Social Science*, *76*, 102025. https://doi.org/10.1016/j.erss.2021.102025

Posner, E., & Adler, M. D. (1999). Rethinking Cost-Benefit Analysis. *Yale Law Journal*, *109*(165).

PRI. (2018). *Implementing the Task Force on Climate-related Financial Disclosures Recomendations*. 21–44. https://www.unpri.org/download?ac=4652

Quiggin, J. (1982). A Theory of Anticipated Utility. *Journal of Economic Behavior and Organization*, *3*, 323–343.

Raj, R., Suman, R., Ghandehariun, S., Kumar, A., & Tiwari, M. K. (2016). A techno-economic assessment of the liquefied natural gas (LNG) production facilities in Western Canada. *Sustainable Energy Technologies and Assessments*, *18*, 140–152. https://doi.org/10.1016/j.seta.2016.10.005

Rasmussen, N. C. (1974). *Reactor safety study: An assessment of accident risks in US commercial nuclear power plants* (Vol. 7). NTIS.

Rechard, R. P. (1999). Historical relationship between performance assessment for radioactive waste disposal and other types of risk assessment. *Risk Analysis*, *19*(5), 763–807. https://doi.org/10.1023/A:1007058325258

Reid, J., Bernhardt, A., Sowden, S., & Lockridge, K. (2021). Mercer: Investing in a time of climate change - the sequel. *World Scientific Encyclopedia Of Climate Change: Case Studies Of Climate Risk, Action, And Opportunity (In 3 Volumes)*, 51–56. https://doi.org/10.1142/9789811213946_0007

Reuters. (2021). *Volkswagen faces EU fine for missing 2020 emissions targets*. 21–23.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a General Theory of Planning (original wicked issues). In *Policy Sciences* (Vol. 4, pp. 155–169).

SBTI. (2021). *From Ambition to Impact: How Companes are Reducing Emissions at Scale with Science-Based Targets* (Issue January).

Schinko, T., Bohm, S., Komendantova, N., Jamea, E. M., & Blohm, M. (2019). Morocco's sustainable energy transition and the role of financing costs: A participatory electricity system modeling approach. *Energy, Sustainability and Society*, *9*(1), 1–17. https://doi.org/10.1186/s13705-018-0186-8

Scordis, N. A., Barrese, J., & Wang, P. (2008). The Impact of Cash Flow Volatility on Cash-Cash Flow Sensitivity. *Journal of Insurance Issues*, *31*(1), 43–71. https://doi.org/10.9790/487x-16134754

Semieniuk, G., Campiglio, E., Mercure, J. F., Volz, U., & Edwards, N. R. (2021). Low-carbon transition risks for finance. *Wiley Interdisciplinary Reviews: Climate Change*, *12*(1). https://doi.org/10.1002/wcc.678

Serafeim, G. (2021). *ESG : Hyperboles and Reality*.

Simmons, R. A., Shaver, G. M., Tyner, W. E., & Garimella, S. V. (2015). A benefit-cost assessment of new vehicle technologies and fuel economy in the U.S. market. *Applied Energy*, *157*, 940–952. https://doi.org/10.1016/J.APENERGY.2015.01.068

Stackpole, B. (2021). *Why sustainable business needs better ESG ratings*. 1–7.

Sven Ove, H. (2018). *Risk* (E. N. Zalta (ed.); Fall 2018). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/sum2017/entries/qm-bohm/#Aca

Tett, G., & Edgecliffe-Johnson, A. (2021). *1 . Inside ESG : Is the $ 1 . 7tn wave of sustainable investing hope or hype ? Receive free Behind the Money updates*. 10–11.

The Global Carbon Project. (2021). *Global carbon dioxide (CO2) emissions from fossil fuels and cement have rebounded by 4.9% this year, new estimates suggest, following a Covid-related dip of 5.4% in 2020*. 1–22.

Tietge, U. (2018). CO 2 emissions from new passenger cars in the EU : Car manufacturers' performance in 2017. *International Council for Clean Transportation*, *July*. https://www.theicct.org/publications/co2-emissions-new-passenger-cars-eu-car-manufacturers-performance-2017

TPI. (2020). *Carbon Performance Assessment of automobile manufacturers*.

Unhedged, O. (2021). *Tariq Fancy is right about the ESG investment industry*. 1–7.

UNPRI. (2015). *Developing an Asset Owner Climate Change Strategy*.

Vaclav Smil. (2018). *Energy and Globalization: A History* (1st ed., Vol. 1). MIT Press.

van Bruggen, A., Nikolic, I., & Kwakkel, J. (2019). Modeling with stakeholders for transformative change. *Sustainability (Switzerland)*, *11*(3). https://doi.org/10.3390/su11030825

van der Spek, M., Fout, T., Garcia, M., Kuncheekanna, V. N., Matuszewski, M., McCoy, S., Morgan, J., Nazir, S. M., Ramirez, A., Roussanaly, S., & Rubin, E. S. (2020). Uncertainty analysis in the techno-economic assessment of CO2 capture and storage technologies. Critical review and guidelines for use. *International Journal of Greenhouse Gas Control*, *100*(July), 103113. https://doi.org/10.1016/j.ijggc.2020.103113

van Dijk, M. A. (2021). *Working paper Assessing climate risk for investment portfolios Working paper Assessing climate risk for investment portfolios*.

Voinov, A., Jenni, K., Gray, S., Kolagani, N., Glynn, P. D., Bommel, P., Prell, C., Zellner, M., Paolisso, M., Jordan, R., Sterling, E., Schmitt Olabisi, L., Giabbanelli, P. J., Sun, Z., Le Page, C., Elsawah, S., BenDor, T. K., Hubacek, K., Laursen, B. K., … Smajgl, A. (2018). Tools and methods in participatory modeling: Selecting the right tool for the job. *Environmental Modelling and Software*, *109*, 232–255. https://doi.org/10.1016/j.envsoft.2018.08.028

Voinov, A., Kolagani, N., McCall, M. K., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A., & Ramu, P. (2016). Modelling with stakeholders - Next generation.

Environmental Modelling and Software, *77*, 196–220. https://doi.org/10.1016/j.envsoft.2015.11.016

Volkswagen. (2020). Volkswagen Group raises investments in future technologies to EUR 73 billion. *Volkswagen Group News*, *272*, 1–5. https://www.volkswagen-newsroom.com/en/press-releases/volkswagen-group-raises-investments-in-future-technologies-to-eur-73-billion-6607

Walenta, J. (2020). Climate risk assessments and science-based targets: A review of emerging private sector climate action tools. In *Wiley Interdisciplinary Reviews: Climate Change* (Vol. 11, Issue 2). https://doi.org/10.1002/wcc.628

Walker, W. E., Lempert, R. J., & Kwakkel, J. (2013). Deep Uncertainty: Uncertainty in Model-Based Decision Support. *Encyclopedia of Operations Research and Management Science*, *1*(1), 395–402. https://pdfs.semanticscholar.org/8e6b/c8cd6c880e54c68e6c1c71a9f9a5a5781283.pdf

WBCSD, & WRI. (2012). A Corporate Accounting and Reporting Standard. In *Greenhouse Gas Protocol*.

Well, M. N. (2021). *The Shocking Truth About Gender Diversity In Investment Management*. 9–12.

Welsby, D., Price, J., Pye, S., & Ekins, P. (2021). Unextractable fossil fuels in a 1.5 °C world. *Nature*, *597*(7875), 230–234. https://doi.org/10.1038/s41586-021-03821-8

Whelan, T., Atz, U., Van Holt, T., & Clark, C. (2018). *ESG and Financial Performance: Uncovering the Relationship by Aggregating Evidence from 1,000 Plus Studies Published between 2015 – 2020*. 520–536. https://www.stern.nyu.edu/sites/default/files/assets/documents/NYU-RAM_ESG-Paper_2021 Rev_0.pdf

Wimbadi, R. W., & Djalante, R. (2020). From decarbonization to low carbon development and transition: A systematic literature review of the conceptualization of moving toward net-zero carbon dioxide emission (1995–2019). *Journal of Cleaner Production*, *256*, 120307. https://doi.org/10.1016/j.jclepro.2020.120307

Wright, C., & Nyberg, D. (2015). *Climate Change, Capitalism, and Corporations*. https://books.google.nl/books?hl=en&lr=&id=XtyCCgAAQBAJ&oi=fnd&pg=PR10&dq=role+of+capitalism+in+climate+change&ots=y3bpLRFkLH&sig=9z53GMP3VfoHtfUP5NkMC7WAW5k#v=onepage&q=role of capitalism in climate change&f=false

Xie, S. P., Deser, C., Vecchi, G. A., Collins, M., Delworth, T. L., Hall, A., Hawkins, E., Johnson, N. C., Cassou, C., Giannini, A., & Watanabe, M. (2015). Towards predictive understanding of regional climate change. *Nature Climate Change*, *5*(10), 921–930. https://doi.org/10.1038/nclimate2689

Yeo, S. (2019). Climate finance: the money trail. *Nature*, *573*(328), 328–333.

Zhou, X., & Kuosmanen, T. (2020). What drives decarbonization of new passenger cars? *European Journal of Operational Research*, *284*(3), 1043–1057. https://doi.org/10.1016/j.ejor.2020.01.018

7 Appendix

7.1 Model setup and data

The model setup consists of the scenario choice from the TPI with an additional Net-Zero scenario. The scenarios are modeled with an exponential decay function, relying on the carbon intensity in 2019 as the initial figure and the carbon intensity in 2050 as the final figure. Table 12 shows the modeled output, split by the scenarios labeled "TPI" and "Robeco SI". Next, the model decline speed for Net-Zero is tested empirically, shown in

Table 13. The model decline speed is denoted as "speed" and is built-in as a selection button in the model. An accompanying chart shows the declining gradient of the net-zero scenario. Table 14 shows the carbon emissions analysis, which is instrumental in operationalizing the Scope 3 use-phase emissions as the carbon intensity measurement. Finally, Table 15 and Table 16 show the model output for convergence and commitment carbon intensity for the 20 OEMs shortlisted for the carbon performance assessment.

Table 12: TPI and Robeco modeled scenario pathways showing their convergence carbon intensity from 2013 to 2050. The projection starts from 2019 as the base year, and figures before that are sectoral historical average, provided using methodology developed by the TPI (TPI, 2020).

Source	**TPI**			**Robeco SI**
Scenario / Year	**2 Degrees (High Efficiency)**	**2 Degrees (Shift-Improve)**	**Paris Pledges [Highest]**	**Net-Zero**
2013	147	147	147	147
2014	145	145	145	146
2015	143	143	143	144
2016	137	137	138	141
2017	131	131	133	134
2018	125	125	128	130
2019	119	119	123	123
2020	113	113	117	105
2021	104	109	116	90
2022	95	105	114	77
2023	86	102	112	66
2024	77	98	111	57
2025	68	94	109	49
2026	62	91	108	42
2027	57	88	107	36
2028	51	84	106	31
2029	46	81	105	26
2030	40	77	104	23
2031	37	74	103	19
2032	34	72	102	17
2033	31	69	101	14
2034	27	67	100	12
2035	24	64	100	10
2036	22	63	99	9

2037	21	61	98	8
2038	19	59	97	7
2039	17	58	96	6
2040	15	56	95	5
2041	14	55	94	4
2042	13	54	93	4
2043	12	52	92	3
2044	11	51	91	3
2045	10	50	91	2
2046	9	49	90	2
2047	8	47	89	2
2048	8	46	88	1
2049	7	45	87	1
2050	6	43	86	~0

Table 13: Model transition speed set up for Net-Zero, since the decay function do not accept 0 as the final value, which results in an undefined function

Asymptote Limit ~0	Power	Speed Level
0.99984375	6400	1
0.9996875	3200	2
0.999375	1600	3
0.99875	800	4
0.9975	400	5
0.995	200	6
0.99	100	7
0.98	50	8
0.96	25	9
0.92	12.5	10
0.84	6.25	11
0.68	3.125	12
0.36	1.5625	13

Table 14: Carbon emissions analysis by scoping for major auto manufacturers, data sourced from CDP

Company	Scope 1	Scope 2	Scope 3	Scope 3 % of Total
Volkswagen AG	4270490	3796231	437578262	98.2%
Toyota Motor Corporation	1904119	3779542	397940000	98.6%
General Motors Company	1589700	3721875	250390993	97.9%
Ford Motor Company	1451947	3068182	184077722	97.6%
Nissan Motor Co., Ltd.	765370	2173236	173481000	98.3%
Honda Motor Co., Ltd.	1240000	3790000	160816499	97.0%

Daimler AG	1239000	1276000	144408800	98.3%
Saic Motor Corporation	3100000	4500000	133076000	94.6%
Groupe PSA	888847	336272	126801341	99.0%
Fiat Chrysler Automobiles NV	1058367	2359103	122750694	97.3%
Renault	626947	585404	100354298	98.8%
Suzuki Motor Corporation	623000	566000	87391000	98.7%
Hino Motors, Ltd.	148100	242406	81156000	99.5%
BMW AG	642259	302574	78102286	98.8%
Volvo	211000	740000	64797000	98.6%
Porsche AG	250000	300000	38726940	98.6%
Volvo Car Group	96000	11000	38382000	99.7%
Mazda Motor Corporation	117120	534950	36336989	98.2%
SUBARU CORPORATION	279674.2	392217.8	35474703	98.1%
Mitsubishi Motors Corporation	116606	416878	35640040	98.5%
BAIC Motor Corporation Ltd	262747	610000	31334000	97.3%
PACCAR Inc	120209	130169	27894453	99.1%
Isuzu Motors Limited	144559	121359	26918413	99.0%
Great Wall Motor Company (H)	0	370000	17380000	97.9%
Dongfeng Motor Group	0	350000	17177500	98.0%
Geely Automobile Holdings	141100	330000	17050700	97.3%

Table 15: Convergence pathway for companies in coverage for carbon performance assessment

	Base year projection																															
Company	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**	**Decay_Rate**
BMW	141.0	127.3	115.0	103.9	93.8	84.7	76.5	69.1	62.4	56.4	50.9	46.0	41.5	37.5	33.9	30.6	27.6	25.0	22.5	20.4	18.4	16.6	15.0	13.6	12.2	11.1	10.0	9.0	8.1	7.4	6.6	6.0	0.90318
BYD	50.0	46.7	43.6	40.7	38.0	35.5	33.2	31.0	28.9	27.0	25.2	23.6	22.0	20.6	19.2	17.9	16.7	15.6	14.6	13.6	12.7	11.9	11.1	10.4	9.7	9.0	8.4	7.9	7.4	6.9	6.4	6.0	0.93389
Brilliance	139.0	125.6	113.5	102.5	92.7	83.7	75.7	68.4	61.8	55.8	50.4	45.6	41.2	37.2	33.6	30.4	27.5	24.8	22.4	20.3	18.3	16.5	14.9	13.5	12.2	11.0	10.0	9.0	8.1	7.3	6.6	6.0	0.90359
Daimler	148.0	133.5	120.4	108.5	97.9	88.3	79.6	71.8	64.7	58.4	52.6	47.5	42.8	38.6	34.8	31.4	28.3	25.5	23.0	20.8	18.7	16.9	15.2	13.7	12.4	11.2	10.1	9.1	8.2	7.4	6.7	6.0	0.90176
Fiat Chrysler	178.0	159.6	143.0	128.2	114.9	103.0	92.4	82.8	74.2	66.5	59.6	53.5	47.9	43.0	38.5	34.5	30.9	27.7	24.9	22.3	20.0	17.9	16.1	14.4	12.9	11.6	10.4	9.3	8.3	7.5	6.7	6.0	0.89641
Ford	158.0	142.2	127.9	115.1	103.6	93.2	83.9	75.5	67.9	61.1	55.0	49.5	44.5	40.1	36.1	32.5	29.2	26.3	23.7	21.3	19.2	17.2	15.5	14.0	12.6	11.3	10.2	9.2	8.2	7.4	6.7	6.0	0.89986
Geely	134.0	121.2	109.7	99.2	89.8	81.2	73.5	66.5	60.1	54.4	49.2	44.5	40.3	36.4	33.0	29.8	27.0	24.4	22.1	20.0	18.1	16.3	14.8	13.4	12.1	10.9	9.9	9.0	8.1	7.3	6.6	6.0	0.90466
General Motors	149.0	134.3	121.1	109.2	98.4	88.8	80.0	72.1	65.0	58.6	52.9	47.7	43.0	38.7	34.9	31.5	28.4	25.6	23.1	20.8	18.8	16.9	15.2	13.7	12.4	11.2	10.1	9.1	8.2	7.4	6.7	6.0	0.90157
Groupe PSA	118.0	107.2	97.4	88.4	80.3	73.0	66.3	60.2	54.7	49.7	45.1	41.0	37.2	33.8	30.7	27.9	25.4	23.0	20.9	19.0	17.3	15.7	14.2	12.9	11.8	10.7	9.7	8.8	8.0	7.3	6.6	6.0	0.90838
Honda	130.0	117.7	106.6	96.5	87.4	79.2	71.7	64.9	58.8	53.2	48.2	43.6	39.5	35.8	32.4	29.3	26.6	24.1	21.8	19.7	17.9	16.2	14.7	13.3	12.0	10.9	9.9	8.9	8.1	7.3	6.6	6.0	0.90554
Hyundai	134.0	121.2	109.7	99.2	89.8	81.2	73.5	66.5	60.1	54.4	49.2	44.5	40.3	36.4	33.0	29.8	27.0	24.4	22.1	20.0	18.1	16.3	14.8	13.4	12.1	10.9	9.9	9.0	8.1	7.3	6.6	6.0	0.90466
Kia	134.0	121.2	109.7	99.2	89.8	81.2	73.5	66.5	60.1	54.4	49.2	44.5	40.3	36.4	33.0	29.8	27.0	24.4	22.1	20.0	18.1	16.3	14.8	13.4	12.1	10.9	9.9	9.0	8.1	7.3	6.6	6.0	0.90466
Mazda	137.0	123.8	112.0	101.2	91.5	82.7	74.8	67.6	61.1	55.2	49.9	45.1	40.8	36.9	33.4	30.2	27.3	24.6	22.3	20.1	18.2	16.5	14.9	13.5	12.2	11.0	9.9	9.0	8.1	7.3	6.6	6.0	0.90401
Mitsubishi Motors	139.0	125.6	113.5	102.5	92.7	83.7	75.7	68.4	61.8	55.8	50.4	45.6	41.2	37.2	33.6	30.4	27.5	24.8	22.4	20.3	18.3	16.5	14.9	13.5	12.2	11.0	10.0	9.0	8.1	7.3	6.6	6.0	0.90359
Nissan	135.0	122.1	110.4	99.9	90.3	81.7	73.9	66.8	60.4	54.7	49.4	44.7	40.4	36.6	33.1	29.9	27.1	24.5	22.1	20.0	18.1	16.4	14.8	13.4	12.1	11.0	9.9	9.0	8.1	7.3	6.6	6.0	0.90444
Renault	125.0	113.3	102.8	93.2	84.5	76.6	69.4	63.0	57.1	51.8	46.9	42.6	38.6	35.0	31.7	28.8	26.1	23.6	21.4	19.4	17.6	16.0	14.5	13.1	11.9	10.8	9.8	8.9	8.0	7.3	6.6	6.0	0.90669
SAIC motor	137.0	123.8	112.0	101.2	91.5	82.7	74.8	67.6	61.1	55.2	49.9	45.1	40.8	36.9	33.4	30.2	27.3	24.6	22.3	20.1	18.2	16.5	14.9	13.5	12.2	11.0	9.9	9.0	8.1	7.3	6.6	6.0	0.90401
Subaru	158.0	142.2	127.9	115.1	103.6	93.2	83.9	75.5	67.9	61.1	55.0	49.5	44.5	40.1	36.1	32.5	29.2	26.3	23.7	21.3	19.2	17.2	15.5	14.0	12.6	11.3	10.2	9.2	8.2	7.4	6.7	6.0	0.89986
Suzuki	104.0	94.9	86.5	78.9	72.0	65.6	59.9	54.6	49.8	45.4	41.4	37.8	34.5	31.4	28.7	26.2	23.9	21.8	19.8	18.1	16.5	15.1	13.7	12.5	11.4	10.4	9.5	8.7	7.9	7.2	6.6	6.0	0.91209
Tesla	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Toyota	119.0	108.1	98.1	89.1	80.9	73.5	66.7	60.6	55.0	50.0	45.4	41.2	37.4	34.0	30.9	28.0	25.5	23.1	21.0	19.1	17.3	15.7	14.3	13.0	11.8	10.7	9.7	8.8	8.0	7.3	6.6	6.0	0.90813
Volkswagen	135.0	122.1	110.4	99.9	90.3	81.7	73.9	66.8	60.4	54.7	49.4	44.7	40.4	36.6	33.1	29.9	27.1	24.5	22.1	20.0	18.1	16.4	14.8	13.4	12.1	11.0	9.9	9.0	8.1	7.3	6.6	6.0	0.90444

Table 16: Commitment pathway for companies in coverage for carbon performance assessment

Company Name	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
BMW	141.0	134.6	128.2	121.8	115.4	109.0	102.5	96.1	89.7	83.3	76.9	70.5	67.0	63.5	59.9	56.4	52.9	49.4	45.8	42.3	38.8	35.3	31.7	28.2	24.7	21.2	17.6	14.1	10.6	7.1	3.5	0.0
BYD	50.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Brilliance	139.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Daimler	148.0	141.8	135.7	129.5	123.3	117.2	111.0	103.6	96.2	88.8	81.4	74.0	65.8	57.6	49.3	41.1	32.9	24.7	16.4	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fiat Chrysler	178.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Ford	158.0	153.1	148.1	143.2	138.3	133.3	128.4	123.4	118.5	113.6	108.6	103.7	98.4	93.2	87.9	82.6	77.4	72.1	66.8	61.6	56.3	51.0	45.8	40.5	35.2	30.0	24.7	19.4	14.2	8.9	3.6	0.0
Geely	134.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
General Motors	149.0	139.7	130.4	121.1	111.8	102.4	93.1	83.8	74.5	65.2	55.9	46.6	37.3	27.9	18.6	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Groupe PSA	118.0	115.3	112.5	109.8	107.1	104.4	101.6	98.9	96.2	93.4	90.7	88.0	83.0	78.1	73.1	68.2	63.2	58.2	53.3	48.3	43.4	38.4	33.5	28.5	23.6	18.6	13.6	8.7	3.7	0.0	0.0	0.0
Honda	130.0	123.8	117.6	111.4	105.2	99.0	92.9	86.7	80.5	74.3	68.1	61.9	55.7	49.5	43.3	37.1	31.0	24.8	18.6	12.4	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hyundai	134.0	128.8	123.7	118.5	113.4	108.2	103.1	97.9	92.8	87.6	82.5	77.3	72.2	67.0	61.8	56.7	51.5	46.4	41.2	36.1	30.9	25.8	20.6	15.5	10.3	5.2	0.0	0.0	0.0	0.0	0.0	0.0
Kia	134.0	128.8	123.7	118.5	113.4	108.2	103.1	97.9	92.8	87.6	82.5	77.3	72.2	67.0	61.8	56.7	51.5	46.4	41.2	36.1	30.9	25.8	20.6	15.5	10.3	5.2	0.0	0.0	0.0	0.0	0.0	0.0
Mazda	137.0	130.8	124.5	118.3	112.1	105.9	99.6	93.4	87.2	81.0	74.7	68.5	65.8	63.0	60.3	57.5	54.8	52.1	49.3	46.6	43.8	41.1	38.4	35.6	32.9	30.1	27.4	24.7	21.9	19.2	16.4	13.7
Mitsubishi Motoı	139.0	132.7	126.4	120.0	113.7	107.4	101.1	94.8	88.5	82.1	75.8	69.5	66.0	62.6	59.1	55.6	52.1	48.7	45.2	41.7	38.2	34.8	31.3	27.8	24.3	20.9	17.4	13.9	10.4	7.0	3.5	0.0
Nissan	135.0	128.9	122.7	116.6	110.5	104.3	98.2	92.0	85.9	79.8	73.6	67.5	64.1	60.8	57.4	54.0	50.6	47.3	43.9	40.5	37.1	33.8	30.4	27.0	23.6	20.3	16.9	13.5	10.1	6.7	3.4	0.0
Renault	125.0	121.0	117.0	113.1	109.1	105.1	101.1	97.2	93.2	89.2	85.2	81.3	77.2	73.1	69.1	65.0	60.9	56.9	52.8	48.8	44.7	40.6	36.6	32.5	28.4	24.4	20.3	16.3	12.2	8.1	4.1	0.0
SAIC motor	137.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Subaru	158.0	149.4	140.8	132.1	123.5	114.9	106.3	97.7	89.1	80.4	71.8	63.2	60.8	58.5	56.1	53.7	51.4	49.0	46.6	44.2	41.9	39.5	37.1	34.8	32.4	30.0	27.7	25.3	22.9	20.5	18.2	15.8
Suzuki	104.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Tesla	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Toyota	119.0	113.1	107.1	101.2	95.2	89.3	83.3	82.1	80.9	79.7	78.5	77.4	74.1	70.8	67.5	64.3	61.0	57.7	54.4	51.2	47.9	44.6	41.4	38.1	34.8	31.5	28.3	25.0	21.7	18.4	15.2	11.9
Volkswagen	135.0	129.4	123.8	118.1	112.5	106.9	101.3	94.5	87.8	81.0	74.3	67.5	64.1	60.8	57.4	54.0	50.6	47.3	43.9	40.5	37.1	33.8	30.4	27.0	23.6	20.3	16.9	13.5	10.1	6.8	3.4	0.0

7.2 Carbon performance assessment scoring methodology

This section explains the methodology used to assess the carbon performance for OEMs in the model. Table 17 shows the input data of company carbon intensity in 2019, company commitment intensity in 2030, and the company convergence pathway intensity in 2030 for Volkswagen. The input feeds into a carbon assessment scoring model, shown in *Table 18*. The carbon assessment scoring model measures current (2019) and future (2030) carbon performance in gCO_2/ km.

Table 17: Carbon performance data map for Volkswagen showing carbon intensity data for 2019, 2025 and, 2030

Carbon performance data map [Use Case: Volkswagen Group]				
Data	**Units**	**Value**	**Description**	**Remarks**
Company carbon intensity 2019	gCO2/ km [NEDC]	119	Reported/ estimated figure	Reported/ estimated figure from TPI. The intensity is based on location sales and type of car sold by drivetrain
Company commitment intensity 2030	gCO2/ km [NEDC]	67.5	Modeled figure	The number is taken by introducing a battery car sales mix of 50% against the current ICE intensity. Assume that ICE intensity does not reduce drastically
Convergence pathway intensity 2030	gCO2/ km	44.7	Modeled figure	The convergence pathway is based on TPI's high-efficiency scenario. The pathway is modeled using a decay function to simulate the accelerated decline in carbon intensity requirement. The accelerated phenomena are supported by the availability of mature technology where diffusivity is already high with pure EV manufacturers in the market.

Table 18: Scoring distribution for current (2019) and forward (2030) looking firm-level carbon performance based on carbon intensity and future commitment

Scoring Type	Year	1	2	3	4	5	6	7	8	9	10	Comments
Current year scoring	2019	150	144	138	131	125	119	89	60	30	0	The TPI's best-case climate trajectory is used to determine the mid-point of scoring- to not punish companies for being in line with climate trajectory. A cutoff for high emitters is set at 150 for the 2019 level. This scale should be dynamic- as the base year should be adjusted yearly for scoring to reflect the latest carbon performance. 2019- figure refers to TPI baseline figure based on the selected scenario
Convergence/ Commitment Delta	2030	40	36	31	27	22	18	13	9	4	0	The commitment delta finds the difference between an OEM's climate target and convergence pathway based on the selected base case scenario. The model sets 40 gCO_2/ km as the best performance, where the commitment delta is zero, awarded 10 points. The 40 gCO_2/ km upper range is determined based on observation on the intensity target distribution, where according to the convergence path, is the upper limit of performance for the OEMs. Therefore, any OEMs with an intensity equal to or lower than 40 gCO_2/ km are awarded 10 points in the future weight, accounting for half the points. Additionally, the lower end of the carbon intensity seems to hover around 80 gCO_2/ km and is therefore attributed for OEMs with intensity more than or equal to 80 gCO_2/ km. Any OEMs with an intensity $\geq$ 80 gCO_2/ km are awarded 1 point. As for the OEMs with intensity between 40 gCO_2/ km and 80 gCO_2/ km, the scores are distributed linearly from 9 to 2 points.

7.3 Transition risk model

This section supplements the thesis report with a fully decomposed view of the transition risk model architecture, consisting of all the model critical elements. Accompanying the model architecture are the data figures in tables *Table 19* and *Table 20*, with categorical distinction, figure units, description, and remarks provided for clarity. Finally, Figure 30, Figure 31, and Figure 32 show the sensitivity analysis output, which runs into more than 396 data output across 12 parametric tests against three policy scenarios.

7.3.1 Transition risk model decomposition

Figure 29: Model decomposition to define transition risk, linking capital and policy risks

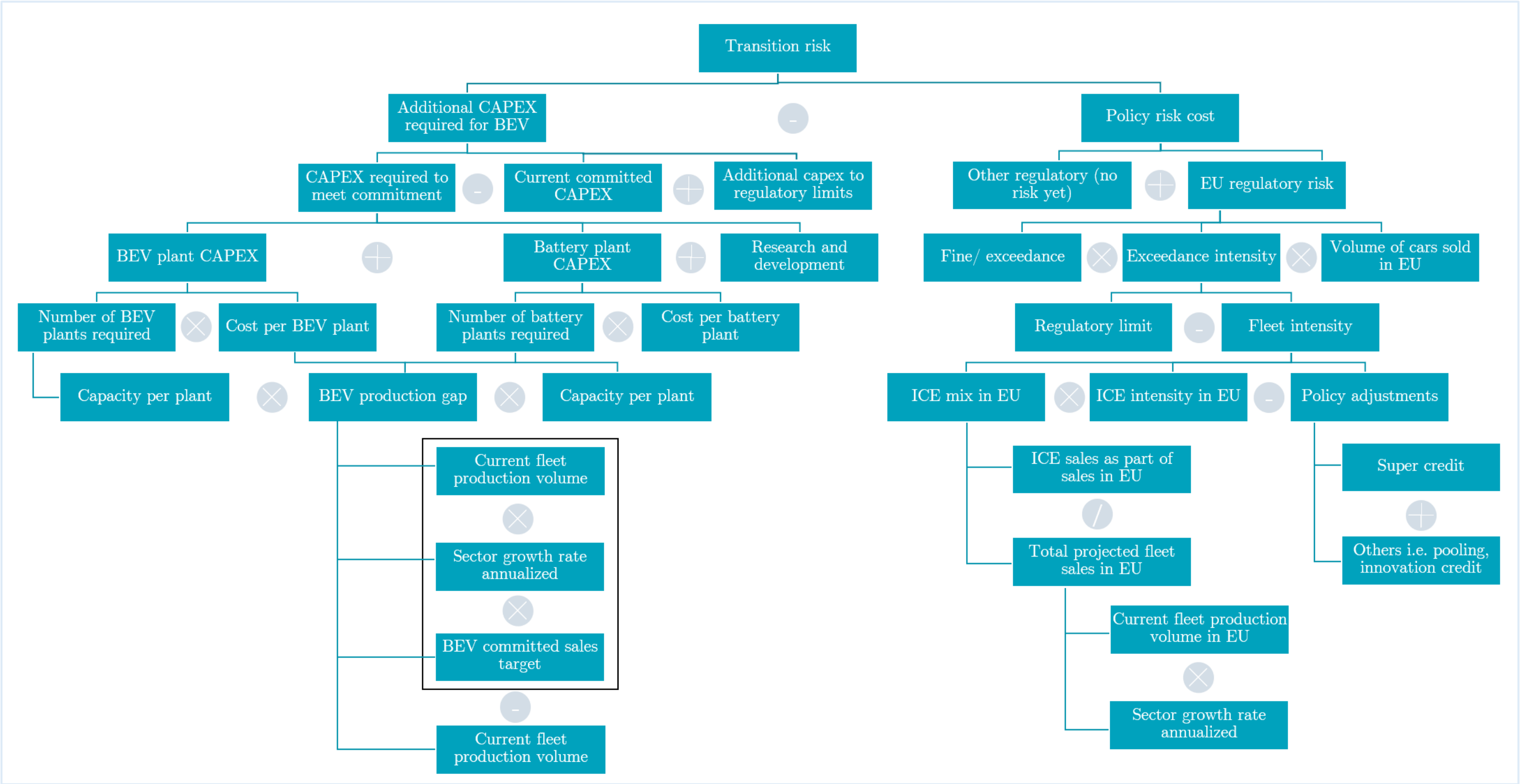


Table 19: CAPEX risk assessment data input, values, descriptions, and remarks (assumptions or special remarks)

Category	No.	Data	Units	Value	Description	Remarks
Production data	1	Production volume 2020	units	9,051,058	Reported figure	Based on 2020 corporate report
	2	Production volume 2025	units	9,993,099	Modeled figure	Based on UBS projection
	3	Production volume 2030	units	11,033,189	Modeled figure	The growth rate is dynamic, but the base case assumes 2% annual compounded growth, starting from 2025.
	4	BEV production mix 2020	%	3%	Reported figure	Based on the 2020 corporate report
	5	BEV Production 2020	units	235,328	Reported figure	BEV mix * total sales
	6	Production mix (convergence) 2025	%	45%	Modeled figure	Based on TPI SDP Pathway
	7	Production mix (commitment) 2025	%	25%	Reported figure	Stated commitment
	8	Production mix (convergence) 2030	%	67%	Modeled figure	Based on convergence figures
	9	Production mix (commitment) 2030	%	50%	Reported figure	Based on commitment figures
CAPEX	10	2025 committed CAPEX for electrification	€	36,500,000,000	Reported figure	The figure includes R&D Spend (not sure about the makeup, but at group level, it is 50%- and at profit and loss level, they are both 6-7% to Revenue Ratio)
	11	R&D absolute	€	18,250,000,000	Reported figure	50% slated for R&D
Production plant input (MEB)	12	CAPEX for electrification	€	18,250,000,000	Reported figure	50% slated for plant CAPEX
	13	Average Production Plant Capacity	units/ plant	300,000	Reported figure	Figure based on VW Group's typical production plant capacity

	14	Cost per MEB plant	€/ [300k units/ year]	2,159,000,000	Reported figure	Reported figure of MEB plant investment in China with 300k annual production capacity with a cost of 17Billion RMB. This figure is converted into Eur based on a 0.127 RMB/ Eur
Battery plant Input	15	Proxy annual battery capacity	Wh	13,500,000,000	Estimated figure	Assuming that battery plants are modular and CAPEX is scalable by capacity
	16	Multiplier for cost proxy	dimensionless	3	Estimated figure	Assuming that battery plants are modular and CAPEX is scalable by capacity
	17	Average cost per 40GWh plant	€	485925925.9	Estimated figure	Assuming that battery plants are modular and CAPEX is scalable by capacity
	18	Average Battery Plant Capacity	Wh	40,000,000,000	Reported	Based on VW Group's standard battery site production capacity
	19	Battery plant capacity	units/ year	444,444	Estimated figure	Based on VW Group's standard battery site production capacity
	20	Power requirement per vehicle	Wh/ unit	90,000	Estimated figure	Average figure based on typical passenger car battery capacity
	21	Battery plant, Eur/ 150000 units/ year cap plant	€	164,000,000	Reported	Based on VW Group's standard battery site production capacity

Table 20: Policy risk assessment model data input, values, descriptions, and remarks (assumptions or special remarks)

Category	No.	Data	Units	Value	Description	Remarks
EU Policy reference	1	Reference mass	kg	1379.9	Reported figure	Based on the EC's stipulated reference fleet mass
	2	Limit value curve slope	kg/ [gCO2/ km]	0.033	Reported figure	Based on the EC's stipulated reference limit value curve slope. This input helps to model firm-level internal targets based on average fleet mass
	3	EU Regulatory Baseline 2020	gCO2/ km [NEDC]	95	Reported figure	Based on the EC's stipulated reference target
	4	EU Regulatory Baseline 2025	gCO2/ km [NEDC]	81	Reported figure	Based on the EC's stipulated reference target
	5	EU Regulatory Baseline 2030	gCO2/ km [NEDC]	59	Reported figure	Based on the EC's stipulated reference target
Production data	6	EU Production volume 2020	units	3493274	Reported figure	Based on reported sales figures by VW Group
	7	EU Production volume 2030	units	4258282	Estimated figure	Estimated to VW Group's 2030 70% EV production target
	8	EU Production Intensity 2020	gCO2/ km [NEDC]	99.8	Modeled figure	Modeled using the intensity estimator
	9	EU Production Intensity 2030	gCO2/ km [NEDC]	44.8	Modeled figure	Modeled using the intensity estimator
	10	Internal fleet target	gCO2/ km [NEDC]	99	Modeled figure	Modeled using the EC's stipulated reference target and slope
	11	Fleet mass 2020	kg	1509	Reported figure	The figure includes the EU’s pooling mechanism

7.3.2 Sensitivity analysis test results

Figure 30: Parametric test against the EU Regulatory Baseline scenario from 2020-2030

Scenario Summary: EU Regulatory Baseline	Base Case	Bad growth no gap	High growth high gap	Base growth no gap	High growth base gap	Low growth high gap	High growth no gap	Low growth base gap	Base growth high gap	Low growth + exceed	Base growth + exceed	High growth + exceed
Changing Cells:												
Company growth	2%	-1%	5%	2%	5%	-1%	5%	-1%	2%	-1%	2%	5%
Gap to productior	-1%	0%	-16%	0%	-1%	-16%	0%	-1%	-16%	2%	2%	2%
Result Cells:	1	2	3	4	5	6	7	8	9	10	11	12
2020	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	1.43	0.67	10.49	0.77	1.65	7.82	0.89	1.23	9.07	0.00	0.00	0.00
2026	0.00	0.00	18.71	0.00	0.00	13.15	0.00	0.00	15.73	0.00	0.00	0.00
2027	0.00	0.00	29.23	0.00	0.00	19.36	0.00	0.00	23.86	0.00	0.00	0.00
2028	0.00	0.00	42.60	0.00	0.00	26.61	0.00	0.00	33.79	0.00	0.00	0.00
2029	0.00	0.00	59.55	0.00	0.00	35.07	0.00	0.00	45.88	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total policy cost	1.59	0.83	160.75	0.94	1.82	102.17	1.06	1.40	128.49	0.17	0.17	0.17

Figure 31: Parametric test against the EU Fit for 55 scenario from 2020-2030

Scenario Summary: EU Fit for 55	Base Case	Bad growth no gap	High growth high gap	Base growth no gap	High growth base gap	Low growth high gap	High growth no gap	Low growth base gap	Base growth high gap	Low growth + exceed	Base growth + exceed	High growth + exceed
Changing Cells:												
Company growth	2%	-1%	5%	2%	5%	-1%	5%	-1%	2%	-1%	2%	5%
Gap to productior	-1%	0%	-16%	0%	-1%	-16%	0%	-1%	-16%	2%	2%	2%
Result Cells:	1	2	3	4	5	6	7	8	9	10	11	12
2020	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2025	1.43	0.67	10.49	0.77	1.65	7.82	0.89	1.23	9.07	0.00	0.00	0.00
2026	0.00	0.00	18.71	0.00	0.00	13.15	0.00	0.00	15.73	0.00	0.00	0.00
2027	0.00	0.00	29.23	0.00	0.00	19.36	0.00	0.00	23.86	0.00	0.00	0.00
2028	0.00	0.00	42.60	0.00	0.00	26.61	0.00	0.00	33.79	0.00	0.00	0.00
2029	0.00	0.00	59.55	0.00	0.00	35.07	0.00	0.00	45.88	0.00	0.00	0.00
2030	0.00	0.00	4.06	0.00	0.00	2.25	0.00	0.00	3.04	0.00	0.00	0.00
Total policy cost	1.59	0.83	164.81	0.94	1.82	104.42	1.06	1.40	131.53	0.17	0.17	0.17

Figure 32: Parametric test against the Volkwagen AG's Convergence Pathway Risk scenario from 2020-2030

Scenario Summary: VW Convergence Pathway Risk												
	Base Case	Bad growth no gap	High growth high gap	Base growth no gap	High growth base gap	Low growth high gap	High growth no gap	Low growth base gap	Base growth high gap	Low growth + exceed	Base growth + exceed	High growth + exceed
Changing Cells:												
Company growth	2.00%	-1.00%	5.00%	2.00%	5.00%	-1.00%	5.00%	-1.00%	2.00%	-1.00%	2.00%	5.00%
Gap to productior	-1.27%	0.00%	-16.00%	0.00%	-1.27%	-16.00%	0.00%	-1.27%	-16.00%	2.00%	2.00%	2.00%
Result Cells:	1	2	3	4	5	6	7	8	9	10	11	12
2020	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2023	2.36	2.12	3.13	2.32	2.57	2.63	2.53	2.16	2.87	2.06	2.25	2.46
2024	3.90	3.40	5.32	3.83	4.38	4.21	4.31	3.46	4.74	3.31	3.73	4.19
2025	5.40	4.09	15.09	4.75	6.25	11.24	5.49	4.66	13.05	3.21	3.72	4.31
2026	6.38	4.16	26.68	4.98	7.59	18.75	5.92	5.33	22.42	2.32	2.78	3.31
2027	6.74	3.57	40.58	4.40	8.25	26.88	5.39	5.47	33.12	0.59	0.72	0.89
2028	6.40	2.27	57.35	2.88	8.07	35.82	3.64	5.04	45.48	0.00	0.00	0.00
2029	5.23	0.18	77.73	0.23	6.79	45.77	0.30	4.00	59.88	0.00	0.00	0.00
2030	0.00	0.00	5.15	0.00	0.00	2.86	0.00	0.00	3.86	0.00	0.00	0.00
Total policy cost	36.40	19.80	231.03	23.40	43.89	148.15	27.58	30.10	185.43	11.49	13.21	15.15