# Taming the Green Swan: How to improve climate-related financial risk assessments

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# Taming the Green Swan: How to improve climate-related financial risk assessments

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Julia Anna Bingler [*]    Chiara Colesanti Senni[†]

July 24, 2020

## Abstract

Climate-related financial risks might have the potential to trigger the next systemic financial crisis, as recently stated by the Bank of International Settlements. In consequence, understanding these so-called Green Swan risks should be a key priority in financial decision-making and supervision. However, a systematic approach and a comprehensive theory on climate-adjusted financial risk metrics is still missing. This study is a first step to fill this gap, with a focus on transition risks. Drawing on insights from climate science, economics and finance research, we derive a set of important criteria to ensure that climate risk tools provide high quality, comparable, and decision-relevant results. We then use a sample of 16 climate transition risk tools and conduct two lines of research: First, by aid of descriptive analysis, we assess the tools' coverage of risk sources and financial assets, their inputs (i.e. underlying climate scenarios), and their outputs (i.e. climate-adjusted financial metrics). Second, we use the previously defined criteria for an in-depth analysis of the quality, comparability and decision-relevance of the tools. The results will be presented at the individual tool level, and at the meta level. Based on the results of our descriptive and criteria-based analysis, we derive potential next steps for tool provider, conclusions for potential tool users, and guidelines for supervisory authorities. The analysis could be used as starting point for building a comprehensive theory of meaningful climate-related financial risk indicators, aid practitioners to select the tools best suited to their needs and use cases, and inform regulatory processes on financial climate risk assessment principles.

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# Abbreviations

**2DII** 2 Degrees Investing Initiative - Paris Agreement Capital Transition Assessment (PACTA)

**2DS** 2 Degrees Scenario

**4DS** 4 Degrees Scenario

**6DS** 6 Degrees Scenario

**B2DS** Below 2 Degrees Scenario

**BIS** Bank of International Settlements

**CAME** Cambridge Econometrics - E3ME-FTT-GENIE

**CAPM** Capital asset pricing model

**CAR4** Carbone4 - Carbon Impact analytics

**CCS** Carbon Capture and Storage

**CFCs** Chlorofluorocarbons

**CFIN** Battiston Monasterolo and Mandel - CLIMAFIN

**$CH_4$** Methane

**CISL** Cambridge Institute for Sustainability Leadership - ClimateWise Transition risk framework

**$CO_2e$** Carbon dioxide equivalent

**EBIT** Earnings before interest taxes

**EBITDA** Earnings before interest taxes depreciation and amortization

**EIA** Environmental Impact Assessment

**ETP** Energy Technology Perspectives

**GLOBIOM** GLobal BIOsphere Management

**HCFCs** Hydrochlorofluorocarbons

**HFCs** Hydrofluorocarbons

**IAMC** Integrated Assessment Modeling Consortium

**IAMs** Integrated Assessment Models

**IEA** International Energy Agency

**IIASA** International Institute for Applied Systems Analysis

**INDCs** Intended nationally determined contributions

**IPCC** Intergovernmental Panel on Climate Change

**IPR** Inevitable Policy Response

**ISS** Institutional Shareholder Services

**ISSE** ISS ESG - Portfolio Climate Impact Report and Raw Data

**KPIs** Key Performance Indicators

**MESSAGEix** Model for Energy Supply Strategy Alternatives and their General Environmental Impact

**MMBOE** Global Industry Classification Standard

**MMBOE** Million Barrels of Oil Equivalent

**$N_2O$** Nitrous oxide

**NACE** Statistical Classification of Economic Activities in the European Community

**NAICS** North American Industry Classification System

**NETs** Negative Emission Technology

**$NF_3$** Nitrogen trifluoride

**$O_3$** Ozone

**OLWY** Oliver Wyman - Climate Transition Risk Methodology

**ORTEC** Oretec Finance - ClimateMAPS

**PFCs** Perfluorocarbons

**PIK** Potsdam Institut für Klimafolgenforschung

**PPE** property plant and equipment

**PwC** PricewaterhouseCoopers GmbH WPG

**PWC** PwC/The CO-Firm - Climate Excellence

**RCP** Representative Concentration Pathway

**REMINDs** Regional Model of Investments and Development

**RIGH** right based on science - X-Degree Compatibility Model (XDC Model)

**SBTI** Science-based Target Setting Tool - SBT Tool and SDA Transport Tool

**SDA** Sectoral Decarbonization Approach

**SDGs** Sustainable Development Goals

**SDS** Sustainable Development Scenario

**$SF_6$** Sulfur hexafluoride

**SPCM** S&P Global Market Intelligence - Climate Linked Credit Analytics for Upstream Oil & Gas Companies

**SPPD** S&P Global Market Intelligence - Climate Linked Credit Risk Tool

**SR15** Special Report on Global Warming of 1.5°C

**SSPSs** Shared Socioeconomic Pathways

**TFCR** Task Force on Climate-related Financial Risks

**TIAM** TIMES Integrated Assessment Model

**UNIA** University of Augsburg - Carbon Risk Management (CARIMA)

**VIVE** Vivid Economics - Climate Risk Toolkit

**WEO** World Energy Outlook

# 1 Introduction

Climate change implies physical, transition and liability risks, which might translate into traditional business and financial risks. One of the most prominently discussed risks in this context is the risk of stranded assets (Caldecott et al., 2016; Gros et al., 2016; Bretschger and Karydas, 2019). Investments in low-carbon technologies, carbon pricing and changing consumption patterns are all phenomena that could affect households and firms cash flows, and hence affect their ability to service debt. As such, climate risks could become a source of financial risk. If the latter are simultaneous or subject to financial market amplification mechanisms, they could lead to financial instability (Battiston et al., 2017; Stolbova et al., 2018; Roncoroni et al., 2019).

Whilst some studies find evidence that the Paris Agreement had an impact on low-carbon and carbon-intensive assets (Monasterolo and de Angelis, 2018), other analyses find that investors are not sufficiently aware of climate risks, and that financial markets currently do not adequately price in emerging climate financial risks (Monnin, 2018b; Campiglio et al., 2019; Karydas and Xepapadeas, 2019a). This means that specific climate-related events and announcements of policies might be included in market valuation. However, since implemented and announced climate policies are not enough to achieve the global climate targets, the full climate transition risks are likely not adequately reflected in financial markets. The lack of historical data, and the various uncertainties surrounding the risk materialisation and scale imply that traditional financial risk analysis frameworks fail to appropriately account for the risks, as prominently highlighted in the widely acknowledged report by the Task Force on Climate-related Financial Disclosures (TCFD, 2017a). A recent report from the Bank of International Settlements and the Banque de France discusses climate-related financial risks as "green swan" risks (Bolton et al., 2020). The relevance of these issues have also been increasingly recognised in the last years at the institutional level, with the implementation of the central bank and financial supervisor's Network on Greening the Financial System (NGFS). Furthermore, the Basel Committee on Banking Supervision recently established a high-level Task Force on Climate-related Financial Risks (TFCR), which issued a first stock take on current initiatives to assess climate-related financial risks (BCBS, 2020). At the national level, supervisory authorities are increasingly taking climate-related financial risks into account, like for example recently announced by the Swiss Financial Market Supervisory Authority (See Hyperlink FINMA 2020).

In this context, developing appropriate tools and methods to deal with these risks has been identified as one of the most important challenges to overcome for financial institutions, central banks, supervisory authorities and researchers (Carney, 2015; Campiglio et al., 2018; Monnin, 2018a). In addition to the often cited "tragedy of the horizon" (Carney, 2015), further key characteristics of climate risks render the appropriate assessment relatively difficult: Traditional risk assessment approaches are mostly based on static or backward-looking data, and usually assume a normal probability distribution of events or shock realisations. However, climate risks are unprecedented, characterised by fat tails, deep uncertainties, non-linearity and path dependency, non-stationarity, and endogeneity (Weitzman, 2011; Chenet et al., 2019; Battiston et al., 2019; Karydas and Xepapadeas, 2019a). As highlighted by research and practicionners (NGFS, 2018; Monnin, 2018b), assessing climate risks requires new foward-looking approaches, which also includes ways to translate transition scenarios into economic outcomes and eventually into financial risk metrics. Climate risk tools from private sector and academia are increasingly available. Yet, if financial climate risk assessments are not of high quality, comparable, and decision-relevant, financial actors will likely fail to efficiently account for climate risks in their investment decisions. This issue has recently been raised by the Net Zero Asset Owner Alliance (See Hyperlink NZAOA 2020).[1] However, a theoretical foundation and systematic approach towards meaningful climate risk indicators is still missing (Semieniuk et al., 2020). As analyses are strongly driven by the underlying assumptions or scenarios of baseline and transition developments, as well as by data input and modelling choices, climate-adjusted financial risk metrics are to date still difficult to use and to interpret. To the best of the authors' knowledge, overview studies on available climate risk tools usually stop at the characteristics description stage. There is no research available which assesses to which extent specific climate risk indicators are empirically meaningful (i.e. capture the most important drivers), whether they are systematically biased, and whether they provide mutually consistent results.

This study contributes to fill this gap. First, we propose a systematic criteria framework to analyse climate-adjusted financial risk indicators. This set of criteria could help potential users to select appropriate tools for their specific use case, and also inform regulatory authorities to define common principles for meaningful climate transition risk analysis for financial institutions. Based on this framework, we undertake an in-depth descriptive and criteria-based analysis of a sample of 16 existing tools to assess climate transition risks for financial decision-making. We report the results of the criteria-based analysis at individual tool level and as a meta study. Our findings show the status quo of climate transition risk tools in the context of financial decision-making, and allow to identify key areas where tools need to be improved. To the best of the authors' knowledge, this study is the first study to provide a comprehensive framework for a criteria-based analysis of climate risk tools, which goes beyond descriptive overviews.

Based on this analysis, we can conclude that few tools cover all analysed risk sources and the interaction among them, more transparency about the assumptions behind the climate scenarios and the modelling approach adopted would be desirable and that tools mostly focus on climate-adjusted financial asset metrics and credit risk metrics for public firms. Morover, we find that transparency of the tools' specific setup is low and that there is a lack of peer-reviewed tool approaches. Considerable variation exists in terms of the depth of risk analysis of the different tools, whereas the existing approaches could be strenghtened by adopting probability distributions for input and outputs. Scenario-neutral approaches, which would allow to use multiple climate models and scenario specifications, are valuable in this regard. Finally, the communication of final outputs in light of key scenario and model assumptions should be improved to ensure interpretability of results. These results provide the basis to identify potential next steps for tool provider, as well as usage guidelines for potential tool users, and for supervisory authorities. We also find that transparency frameworks to report climate risk tool structures and climate risk tool outputs would be key towards enabling high quality, comparable, and decision-relevant climate risk analyses for investments and financial supervision.

The report is organized as follows: Section 2 provides the conceptual background of climate-adjusted financial risk assessments. The study sample and our methodology are described in Section 3. Section 4 describes the analysis criteria and the associated assessment elements. The results of our descriptive and criteria-based analyses are reported in Section 5. Finally, Section 6 summarises key findings and Section 7 identifies potential the next steps for tool provider, tool

[1]The Net-Zero Asset Owner Alliance is an UN-backed alliance of 25 institutional investors with $4.7 trillion assets under management, committed to transition their investment portfolios to net-zero GHG emissions by 2050 (See `https://www.unepfi.org/net-zero-alliance/` for further details).

users and regulators. In addition, we provide extensive background information on all analysed tools in the Appendix.

# 2 Background

Climate change and the consequent introduction of climate policies could impact the financial sector through physical risks, transition risks and liability risks (Carney, 2015; TCFD, 2017a). In the present study, we focus on transition risks. Physical risks[2] and liability risks[3] are not explicitly part of this study. However, the ability of climate risk tools to accommodate for physical risk is documented in the further use analysis section 5.3.

The following Sections provide a general overview of the most important elements of financial climate risk analysis: Climate transition scenarios (Section 2.1), common financial risk and valuation metrics (Section 2.2), important definitions (Section 2.3) and climate risk indicators and tools (Section 2.4). Furthermore, we briefly outline the relation of financial climate risk assessments to climate alignment assessments (Section 2.5.1), to the EU taxonomy (Section 2.5.2) and to general ESG analyses (Section 2.5.3). A more in-depth discussion of the various relevant aspects in the context of financial climate transition risks is provided in the Criteria Section 4.

## 2.1 Climate transition scenarios

Climate models usually work with (remaining) emission budgets, which allow to achieve a certain temperature target.[4] The emission budgets are allocated over time, geography and sectors to model a possible path to stay within the emission budget and hence fulfil the selected temperature target at a certain likelihood (usually 66%). Different approaches to allocate the emission budget, various assumptions and model calibrations result in different emission (reduction) trajectories over time. These different trajectories can than be used for best case, worst case and most likely scenario analyses for the economic and financial impact modelling. Climate scenarios are hence the result of a variety of modelling choices, which reflect various assumptions about future socio-economic and technological developments. Figure 1 provides a schematic illustration of how a specific temperature target is translated into a transition scenario, given specific assumptions and using a specific climate model.

Usually, models are calibrated using current policy, technology and socio-demographic data. Models can be run several times to show how the system and key variables evolve over time,

[2]The physical risks arise from climate-related shocks or continuous changes, such as droughts, wildfires, floods, storms and sea-level rise. Such risks can generate financial instability as they might affect the cash flows of companies through, for instance, disruptions in the production chain. This, in turn, reduces the ability of companies to repay their loans and thus expose banks to higher credit risk and increases their probability of default. As illustrated in Dietz et al. (2016), Dafermos et al. (2018) and Bovari et al. (2018), such events can significantly endanger the value of financial assets in the economy. For example, Dietz et al. (2016) estimate the global climate value at risk at approximately USD 24 trillion. Similarly, the Stern Report (Stern, 2007) states that up to 20% of GDP by end of the century could be lost. Moreover, the publication date shows that these insights are by no means new, but measures to account for economic and financial risk exposure have not been widely adopted yet.

[3]Liability risks arising from the potential impact of legal actions by parties suffering from climate change against those held responsible are also widely discussed among policymakers and practitioners (Carney, 2015; Weber and Hösli, 2019; Hösli and Weber, 2020).

[4]The allocation of the emission budget can be informed by various considerations. To discuss the underlying targets (for example equity, equality, or fairness) and implementation mechanisms (for example global uniform carbon pricing, differentiated carbon prices, sectoral budgets, linear reduction factors etc) would go beyond the scope of this paper. However, it is important to note that the allocation of the carbon budget is the main driver of climate transition risks, and should be selected carefully.

given specific assumptions, to achieve the given target. Joint sets of such assumptions are for example the so-called Shared Socioeconomic Pathways (SSPs) (O'Neill et al., 2017). They have been developed to ease comparability of various climate model results in the IPCC's Special Report on 1.5°C. For financial risk analyses, the NGFS, together with the Potsdam Institute for Climate Impact Research (PIK), the International Institute for Applied Systems Analysis (IIASA), the Joint Global Change Research Institute–University of Maryland, Climate Analytics, and ETH Zurich, just published a set of reference scenarios available to be used in financial risk analyses (NGFS, 2020b,a). The consortium furthermore launched an open source platform for joint reference climate change scenarios, to be used in climate-related financial risk analysis (See Hyperlinks: NGFS Scenarios Documentation, IIASA NGFS Scenario Explorer Database).

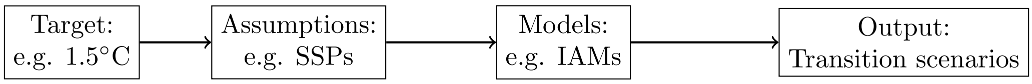


Figure 1: Schematic overview on the translation of climate targets into transition scenarios

Besides general socio-economic assumptions, important modelling decisions in the context of financial risk analyses are the following: First, the temperature target itself. Rogelj et al. (2018) show, for example, that - given the same assumptions - the world would have to be decarbonised on average 20 years earlier for the sample of considered 1.5°C scenarios, compared to the corresponding 2°C scenarios. This bears important implications on investment decisions, given the lifetime of most physical assets.

Second, the implied emission trajectory has important implications on investments. The trajectory is characterised by the overall emission budget of the respective sector in a respective region, the year of the emission peak, and whether and when net-zero emissions or full decarbonisation would be achieved. A later emission peak would, for example, mean that carbon-intensive investments are less risky in the short term, but a very steep (and potentially shock-like) decarbonisation of the economy would have to follow afterwards, in order to stay within the Paris Agreements' temperature limits (Rogelj et al., 2018). Furthermore, the emission trajectory looks different with emission or temperature overshoot, which, in turn, requires more negative emission technologies (NETs) and carbon capture and storage (CCS) investments.

Third, assumptions relating to economic and technological developments of GHG mitigation and removal options, as well as the future development of nature-based carbon sinks are important. These assumptions are informed by technological and economic developments, but also by the risk appetite of the scenario user. For example, (Chenet et al., 2019) argue for a precautionary approach with emission peaks as soon as possible, low reliance on CCS and unproven technologies, and no temperature or emission overshoot. However, at the same time, scenario selections are often constrained by practical considerations. The IEA for example provides to date the most granular scenarios - however, they have a relatively high reliance on CCS and NETs, and the decarbonisation sets in at a relatively late point in time, compared to other scenarios. It would be beyond the scope of the present analysis to dig deeper into the debate surrounding these considerations. Still, in any case - be it higher reliance on GHG mitigation, or on GHG removal - requires significant investments in technological and/or natural capital. Hence, it is important to be aware of the type of investments that needs to be scaled up for the correct interpretation of climate risk analysis results.

Fourth, related to the above point, policies, technological options and developments for GHG mitigation and GHG removal differ across sectors. Sector-specific analyses might miss out on trade-offs, if the rest of the economy is not taken into account in the climate scenarios. For example, the services sector is considered as 1.5°C aligned in most scenarios, already today. However, if full decarbonisation until 2050 would be the target, and given that some process emissions of heavy industries will be relatively difficult to tackle technically, the services sector might have to fully decarbonise earlier, to enable the global economy to stay within the required carbon budgets. Such sector budgets are important for informed investment decisions - yet few jurisdictions identify legally binding sectoral targets, which would be useful to inform the sectoral analyses.

For example, to illustrate some of the above points, the IPCC states that for 1.5°C pathways with no or limited overshoot, the global primary energy supply share from coal decreases to 1–7% by 2050, with a large fraction of this coal use combined with carbon capture and storage (CCS) (Rogelj et al., 2018). Taking the UNFCCC's principle of common but differentiated responsibility into account, the share of coal in the energy mix in 2050 in industrialised countries would likely drop to the lower end of the scale. Furthermore, unprecedented transitions in land use are projected by the IPCC, with significant challenges to deal with competing demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (Rogelj et al., 2018).

Furthermore, physical climate risks and transition risks are interlinked. For example, more mitigation measures increase transition risk, but reduce physical risks. The NGFS scenarios account for this fact, and it is likely that future climate risk tools increasingly take this trade-off into account (NGFS, 2019, 2020b). Still, it needs to be considered that the trade-off might hold at global level. At the individual asset level, a certain asset or business activity could be subject to tight emission policies in one region, and, at the same time, exposed to high physical climate risks resulting from the global nature of climate change. Hence, ideally, scenarios combining physical and transition risks would differentiate by region.

It would be beyond the scope of the present analysis to discuss in detail the importance of appropriate scenario selection for climate-related financial risk analyses. More in-depth reports on scenario selection for financial decision-making and climate risk analysis are available from the from the NGFS (NGFS, 2020a), the Energy Transition Advisers for PRI (ETA, 2020), the Institutional Investors Group on Climate Change (IIGCC, 2019), and the TCFD (TCFD, 2017b).

## 2.2 Financial risk metrics

In order to be able to consider climate risks in financial decision-making, these are ideally translated into standard financial risk and valuation metrics. Financial risk and asset valuation are closely linked. They are important identify the right price and value of an asset, especially when it is bought or sold. Moreover, correct asset valuation matters for tax declarations and loan applications, mainly when the bank or financial institution may require collateral as protection against possible debt default. Financial risk analysis generally aims at assessing the likelihood and impact or severity of an adverse event occurring (Aznar Siguan and Bresch, 2019). The output of financial risk analysis are financial metrics, which can be used for financial asset valuation, firm valuation or credit risk assessment. Given the scope of the present work, we describe most important risk and valuation metrics, which are relevant for the analysis of climate-adjusted financial risk indicators in Table 1. The Table serves to provide general background information. We do no aim to provide a exhaustive description of all the existing financial risk and valuation metrics.

| Financial risk / valuation metric | Explanation |
|---|---|
| **Firm valuation** | |
| Firm value (market cap/EV) | Various fundamentals- or market-based approaches. For example: Market capitalization of a company, that is, the current price of its stock times the number of outstanding stock shares; or Enterprise Value (EV), which considers market capitalization and short-term and long-term debt of the company, as well as the liquid assets of the company (cash). |
| Cost of capital | Weighted average of the cost of debt, that is, the interest rate paid by the company to its lenders, and the cost of equity, which is the rate of return demanded by equity investors. |
| Liquidation assets value | Total worth of a company's physical (but not intangible) assets if they were sold. |
| **Financial asset risk / valuation metrics** | |
| Asset price | Value of the asset is determined by its market price or its projected price when sold in the open market |
| Expected returns | Amount of profit or loss an investor anticipates to obtain over the investments' lifetime or until maturity (i.e. usually a probability weighted average of the rates of return of various scenarios) |
| Expected dividends | Expected dividend payments to stock holders |
| Alpha | Shows the delta of how well an investment has performed against a given benchmark index, measured in returns. See Jensen (1969) for an academic reference. |
| Beta | Measure of the volatility of an investment, it indicates how volatile a stock's price has been in comparison to the market as a whole. Hence, Beta is an indicator of the relative risk of an investment, with a value of one if the security is perfectly correlated with the market. See Levy (1971) for an academic reference. |
| CAPM factor | Provide predictions of the relationship that we should observe between the risk of an asset and its expected return. This relationship provides a benchmark rate of return for evaluating different investments and allow to make an educated guess about the expected return of an asset which is not yet traded on the market. See Sharpe (1964), Lintner (1975), Mossin (1966) for academic references. |
| Standard deviation | Measure of the uncertainty of outcomes as squared deviations from the mean value of the return on an asset. |
| R-squared | Percentage of an asset price variation that can be explained by movements in a benchmark index. |
| Sharpe ratio | Captures the trade-off between reward and risk of an asset, computed as the ratio between the risk premium (i.e. the average excess return) and the standard deviation of its excess return. See Sharpe (1966), Sharpe (1994) for academic references. |
| Sortino ratio | Ratio of average excess returns to the lower partial deviation (LPSD). For non-normal return distributions.[6] See Sortino and Price (1994), Sortino (2009) for academic references. |
| Value at risk | The maximum loss on a position or portfolio at a specified probability level (known as the confidence level) over a specified horizon. |
| Maximum drawdown | Maximum observed loss from a peak to a trough of a portfolio, before a new peak is attained compared to a benchmark. |
| **Credit risk assessment** | |
| Probability of default | Likelihood of a default over a particular time horizon. |
| Loss given default | Amount of the loan which will be lost in case that a default occurs. |
| Value of collateral | Market value of the assets used by the company to secure a loan and reflects the risk for a lender of granting a loan. The value is determined by looking at the recent sale prices of similar assets or by following the judgment of experts. |
| Distance to default (Merton) | Credit risk of a company, based on the assumption that the firm defaults when the real value of its assets is below the value of its debt at the time of the maturity of the debt. See Merton (1974) for an academic reference. |
| Credit rating | Evaluation of the credit risk of borrowing institutions or specific products, as determined by credit rating agencies. |

Table 1: Financial risk / valuation metrics

### 2.3 Climate risk analysis

Financial decision-making requires that climate risks are reflected in standard financial risk metrics. This encompasses the consideration of various climate risk-related aspects, from transition risk sources to economic climate risk indicators and climate-adjusted financial risk indicators. Depending on the use case, various risk channels are relevant (Krueger et al., 2020). The TCFD and NGFS risk schemes can be used as starting points to understand the relevant risk channels[7]. In this

[7]See TCFD 2017, p.8; NGFS 2019, p.17 and NGFS 2020, pp.9-12.

context, key terms are often used interchangeably due to the general lack of conceptual background and concise theoretical considerations in this field. To contribute to a meaningful climate-adjusted financial risk indicators theory, we provide short descriptions to differentiate between economic climate risk indicators, climate-adjusted financial risk indicators, and climate risk tools.

**Economic climate risk indicators** are specific climate-related indicators that summarize usually the exposure of an economic entity to climate change[8] and/or climate change-related developments. This means that these risk indicators are usually not financial indicators, and usually do not cover all relevant aspects of risk (cf. Section 4.2). Current and expected GHG emission are the most widely used economic climate risk exposure indicators. In this context, CAPEX and OPEX are important sources of information to estimate future GHG emissions, and cross-check the reporting of current GHG emissions.

**Climate-adjusted financial risk indicators / metrics** are standard financial risk indicators (metrics) used for financial decision-making, adjusted by taking the impact of climate risks of the underlying assets and issuer into account. These include, for instance, the climate-adjusted value at risk, or, alternatively, the climate-adjusted expected loss. Throughout the paper, we use the terms climate-adjusted financial risk indicators and climate-adjusted financial risk metrics interchangeably.

**Climate risk tools** are tools used to assess the economic and/or financial impact of physical and/or transition climate risks.[9] Financial climate risk tools usually translate economic impacts into climate-adjusted financial risk indicators. The next Section provides a more detailed description of these tools.

## 2.4 Financial climate risk tools

There are two main ways to translate climate scenarios into economic and financial impacts: Regression analysis and deterministic modelling.[10] The structure of the tools could have a significant impact on the analysis outcome. This is why the present report focuses on the analysis of these tools. The following Section focuses on deterministic modelling, since this is most widely used by the tools analysed in the present study. Given the climate scenario output, the economic modelling can be done either with a top-down, or with a bottom-up approach. The main difference between both approaches is whether the output of the climate scenario directly affects the firm, or whether the firm is indirectly affected via sectoral or economy-wide impacts. Bottom-up approaches are usually more granular and the results are likely more reliable for the near term, whereas top-down approaches tend to be more reliable for the medium- to long term. For illustrative purposes, Figure 2 displays a generic financial climate transition risk assessment tool with a top-down deterministic structure. A bottom-up model would be similar, yet without the macroeconomic model component.

[8] In this case, the indicators capture physical risks, for example in the form of exposure (the physical asset location), expected hazard (e.g. more intense tropical storms), and vulnerability and adaptability (for example local adaptation measures like building retrofitting).

[9] The measures that climate risk tools use to capture exposure to transition risk could in some cases also be adopted to account for litigation/liability risks. However, since litigation risks add another level of complexity to the analysis, they were not included in the present study.

[10] Due to the lack of a scientific financial climate risk analysis theory, this Section builds, amongst others, on insights from bilateral consultations with Truman Semans, OS-climate.

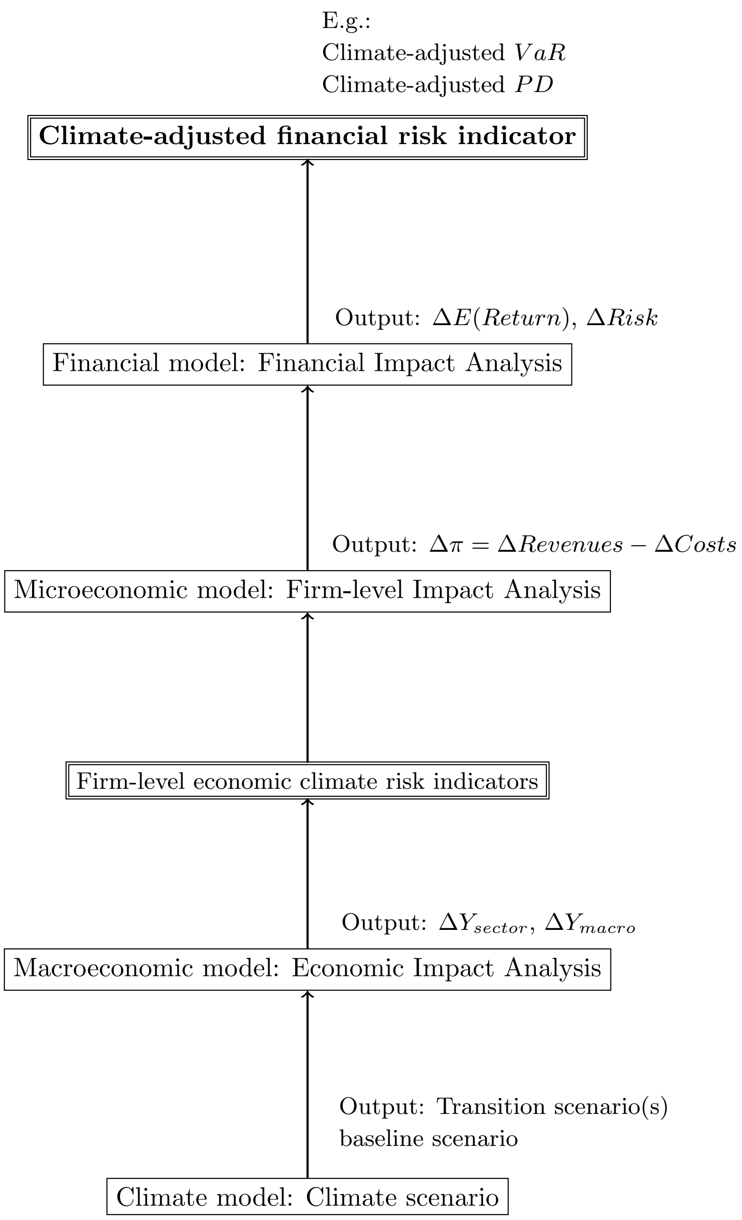


Figure 2: Example for climate risk tools' generic structure (top-down, deterministic approach). $VaR$: Value-at-Risk, $PD$: Probability of Default, $\Delta$: the variation in the variable considered, $Y$: economic activity, $\pi$: profits.

**1. Climate scenarios** provide the emission trajectory required to limit global warming to a certain temperature or the implied temperature increase of a certain carbon emissions development. This given, they provide the potential transition, and the potential baseline developments for the climate risk analysis.[11] Risk tools can include smooth or shock transition scenarios. In the first case, a gradual adjustment of the economy is foreseen, including for instance a gradual phase out of fossil fuels. Actors would have the possibility to anticipate the changes, and decide accordingly for example when undertaking investment decisions. This would limit the risk of stranding assets (Bretschger and Soretz, 2018). In the second case, the economy would experience a "hard landing" transition with constrained energy supply and increased costs of production for the whole economy, with effects equivalent to a large and persistent negative macroeconomic shock (Gros et al., 2016). The present study analyses the covered risk sources, risk realisations, and employed climate models to the derive the climate scenarios by tool in detail in Sections 5.1.1 and 5.1.3 .

**2. The economic impact analysis** at the macroeconomic or sectoral level takes the outputs from the climate scenario analysis as inputs to model macroeconomic changes. For example, the climate scenario might dictate that the power sector should be decarbonized by 2050 in order to achieve a given temperature target. The general economic implications are for example to quantify low-carbon investments required, carbon-intensive divestments required, shifts in the economic structure, and changes of gross productiona and GDP. The economic activity analysis has an impact on the firm-level economic analysis in top-down tools. In bottom-up tools, this step is skipped. The climate transition scenario implications directly translate into the firm-level economic analysis. The extent to which macroeconomic changes are covered by tools is analysed in Section 5.2.2.

**3. The firm-level impact analysis** uses firm-level economic climate risk indicators as inputs to compute the expected changes in revenues, costs, and associated profit and cash-flow variations under the specified transition scenario (bottom-up tools) or based on the economic activity analysis (top-down tools). For the present study, we use a risk concept rooted in the physical climate risk and adaptation science (ECA, 2009; Bresch et al., 2014), and combine it with insights from microeconomic theory. This allows us to apply the climate risk concept to firm-level climate transition risk analyses. The specific firm-level risk aspects exposure, vulnerability and resilience, adaptability, and economic impact are explained in more detail in Section 4.2. These are used to various extent in the tools to model the transition-induced expected change for most important microeconomic variables. The depth of risk analysis is a core dimension of the present report, and described in more depth in Section 2.1. The results are reported in detail in Section 5.2.2.

Using standard microeconomic theory (Varian, 1992), we know that

$$\Delta\pi = \Delta Revenues - \Delta Costs, \tag{1}$$

[11] Note that a baseline scenario is not necessarily a business-as-usual scenario. There is widespread scientific agreement that with climate change, there is no business-as-usual in the future (IPCC, 2014; Rogelj et al., 2018). Hence, such scenarios are not meaningful for the mid- and long term. Most tools refer to the business-as-usual as a situation in which current policies are kept in place, but no additional measures are introduced. This would have significant implications for the trade-off between physical risks and transition risks: Transition risks might be lower, but such a "business-as-usual" scenario would ideally be able to include higher physical risks. The status quo as baseline scenario or assumption is only meaningful for very short term analyses.

where $\Delta$ represents the transition-induced change in the variable considered, and $\pi$ is profits. Moreover,

$$\Delta Revenues = f(\Delta P, \Delta Q), \tag{2}$$

where $\Delta P$ is the transition-induced change in the good's wholesale price, and $\Delta Q$ the transition-induced change in the good's produced quantity. $\Delta P$ depends positively on the cost pass-through. The cost pass-through is higher, the lower the elasticity of demand and the lower the level of competitiveness in the good market. Furthermore,

$$\Delta Costs = f(\Delta C_{Fix}, \Delta C_{Variable}, \Delta Q), \tag{3}$$

where $\Delta C_{Fix}$ is the transition-induced change in fix costs, and $\Delta C_{Variable}$ is the transition-induced change in variable costs. These can vary with the inputs used, and the quantity produced. The costs are determined by the quantity produced, the production inputs for each unit of production, and the production technology. These elements are captured by the production function. Hence, current and expected OPEX and CAPEX are important inputs to assess the firm-level climate risk.

**4. The financial impact analysis** then translates the firm-level economic impacts into climate-adjusted financial performance indicators. The change in the underlying probability distribution is a very important determinant to derive climate-adjusted financial metrics. For example, the climate-adjusted risk and expected return can be determined by aid of scenario analysis, which generates a probability distribution of potential return realisations:

$$E(Return) = \sum\nolimits_{i=1}^{N} Return_i p_i \tag{4}$$

where $E(Return)$ is the (climate-adjusted) expected return, with $Return_i$ the return in scenario i and $p_i$ is the transition-adjusted probability for the $Return_i$, and $N$ is the total amount of transition scenarios considered.

Depending on the use case, the *changes* in expected return could be more important. In this case, we would have

$$\Delta E(Return) = \sum\nolimits_{i=1}^{N} Return_i \Delta p_i \tag{5}$$

where $\Delta E(Return)$ is the transition-induced change in expected return, compared to the baseline, and $\Delta p_i$ the change in the probability for the $Return_i$ in the transition scenario i, compared to the probability for the same amount of return in the baseline.[12]. The associated transition-induced change in the financial risk $\Delta Risk$ is then for example the change of the variance in the climate-adjusted probability distribution of returns, or another appropriate financial risk measure.

[12]Note that this analysis can also be conducted using $\Delta Return_i$, at given probabilities

Similarly, a transition-induced change in expected losses ($\Delta EL$) could for example be calculated as the product of the transition-induced change of the probability of default ($\Delta PD$), the loss given default ($LGD$) and the exposure at default ($EAD$):

$$\Delta EL = \Delta PD \times LGD \times EAD \tag{6}$$

There are multiple options how to translate economic impacts into climate-adjusted financial risk metrics. Depending on the use case and the covered asset class, these can be climate-adjusted asset prices (determined by adjusted risk/return profiles), probability of default, Value-at-risk, credit ratings, or others. The present study analyses the coverage of potential use cases, as determined by the asset class (see Section 5.1.2), and the type of climate-adjusted financial metrics provided as output by the tools (see Section 5.1.4).

## 2.5 Further concepts

### 2.5.1 Relation to climate alignment, impact and target setting tools

Although some of the tool providers cover multiple use cases, climate risk analysis differs from climate alignment, impact and target setting analyses in various dimensions. First, risk analysis serves a different target. Alignment and impact analyses could play a role in this context, but do not have to. For example, an assessment of (mis-)alignment would be one strategy to identify risk exposure, and alignment activities could be a risk management strategy to reduce the exposure. However, (mis-)alignment itself does not capture the further risk aspects of vulnerability and resilience, adaptability, and economic impact. Second, alignment and target setting tools are directly related to a certain temperature goal, usually the Paris Agreement's climate target of $1.5/<2°$C. In contrast, risk analyses should be informed by a variety of temperature trajectories. This allows to derive a probability distribution of potential outcomes, which is more appropriate for risk analyses. Third, the key metrics for assessment are different. For risks, it is a climate-adjusted financial metric. For alignment, it can be various technology-, emission-based, or economic metrics (Institut Louis Bachelier, 2020). Nevertheless, alignment, impact and target setting analyses could overlap with or could be an input to risk analysis. Furthermore, the full set of climate-related analyses could be useful to identify and monitor climate risk management strategies. Therefore, the concepts need to be clearly distinguished, although the different types of tools can be used in a complimentary way.

**Climate alignment tools** cover the extent to which a certain business activity is aligned with a specific transition scenario. The degree of misalignment or the gap between alignment and misalignment can be used as a proxy for transition risk exposure.[13]

**Climate impact tools** assess the GHG emissions associated with a certain economic activity. They hence implicitly cover risks, at least to a given extent. For example, a higher climate impact means higher exposure to mitigation policies (including low-carbon related market upstream and downstream policies or developments).

[13] A recent study by Institut Louis Bachelier (2020) provides an in-depth overview over climate alignment tools.

**Climate target-setting tools** are designed to help economic actors to define a climate strategy. These tools are sometimes alike alignment tools, yet they are not the same, especially for financial actors. Whilst financial institutions could align their portfolio with the climate targets by re-allocating their investments, there is an ongoing debate about whether target setting for financial institutions to realise GHG emission savings in the real economy is feasible at all.[14] However, the output of target setting tools could be used for real economy firms as input to assess an investee's adaptability to transition developments.

### 2.5.2 Relation to the EU Taxonomy

Two main aspects of the EU Taxonomy and the associated EU Taxonomy Regulation are relevant in the context financial climate risk analysis. First, on a conceptual basis, its bottom-definition of economic activities for key sectors, including agricultural, land use and waste management activities, which would contribute to achieve the climate goals. Second, with regards to data availability, its disclosure provisions for large companies.

In its current status, the EU Taxonomy is a tool to assess the contribution of economic activities to environmental goals, starting with climate change mitigation and adaptation.[15] It follows a bottom-up approach, with a technology-based assessment at the individual production asset level by business activity (NACE-classification). To date, technical screening criteria for 70 climate change mitigation and 68 climate change adaptation activities are available (TEG, 2020b). In addition, the EU Commission provides an excel tool to foster the market uptake of the taxonomy (See Hyperlink: EU Taxonomy excel tool). Key climate transition-relevant sectors are included, amongst others agricultural, land use and waste management activities (which are currently not sufficiently covered by the majority of climate risk tools). Thus, it could be used for a first risk exposure screening, if it is assumed that all activities, which do not contribute to achieving the climate goals, would be exposed to higher transition risks. Or, vice versa, if investors assume that activities, which contribute to achieving the environmental goals, are exposed to lower risk of becoming stranded (physical, economic and financial) assets. However, to date, the Taxonomy does not differentiate between economic activities, which do not contribute to achieve certain environmental goals (including the climate goals), and activities, which hinder achieving the goals. The risk exposure would likely differ between these two types of activities. This is why the TEG called in its final report for a corresponding taxonomy to classify non-aligned or environmentally harmful activities (TEG, 2020a). Indeed, the Taxonomy Regulation provides the option to develop such a non-alignment ("brown") taxonomy. The schematic overview in Figure 3 provides a first intuition how the current Taxonomy, and the potential non-alignment Taxonomy, might be used for climate risk exposure screenings by investors.

[14]Due to the lack of direct control over the investee's GHG emissions, some actors argue that financial institutions could only define actions they want to pursue (for example, engagement activities), but they cannot claim to pursue and fulfil a certain GHG emissions mitigation target. The debate has not been solved, yet, and the development of target setting tools for financial institutions is still ongoing (cf. recent discussions involving the 2 degrees investing initiative, the Science-Based Targets Initiative, PCAF, Terra, and others)

[15]The EU Taxonomy defines metric performance thresholds at the technology/production asset level, by economic activity. The activities should (1) make a substantive contribution to environmental objectives, and (2) avoid significant harm to other EU environmental objectives. In addition, activities need to meet minimum safeguards (e.g., OECD Guidelines on Multinational Enterprises and the UN Guiding Principles on Business and Human Rights). The criteria were developed by a technical expert group, starting with climate change mitigation and climate change adaptation, and will be further extended to biodiversity, water, pollution, and circular economy (TEG, 2020a). The performance criteria will be regularly reviewed - at least every third year - by the multi-stakeholder Platform on Sustainable Finance.

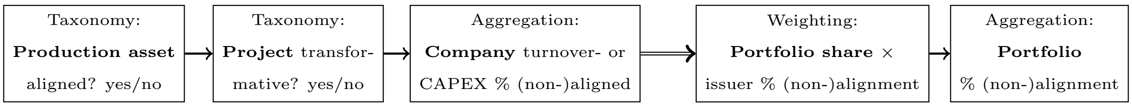


Figure 3: Schematic overview on using the EU Taxonomy for portfolio climate risk exposure screenings

Second, the Taxonomy Regulation requires all real economy companies, which are subject to the Non-Financial Reporting Directive, to report their share of taxonomy-aligned turnover, CAPEX, and - where appropriate - OPEX. These two key variables are important data for forward-looking financial climate risk analysis, and allow investors to track the credibility and performance of a company against with regards to its climate targets and over time. In addition, investors will be required to also disclose the proportion of financing of transition activities (i.e. economic activities, which are currently non-aligned, but in transition towards alignment) and enabling activities (i.e. activities, which are themselves not necessarily aligned with the environmental goals, but enable other actors to contribute to achieve environmental goals). Given the large share of investments into other financial market actors, this could potentially allow investors to better capture the climate risks of their financial sector investments, and the entire portfolio. The European Commission plans to adopt a delegated act on the specific corporate disclosure obligations by 1 June 2021, differentiating between non-financial and financial companies (TEG, 2020a).

### 2.5.3 Relation to ESG analyses

An important distinction exists between economic and climate-adjusted financial risk indicators, and general environmental, social, governance (ESG) indicators. The latter are usually in the form of ratings, that is, they show the ESG performance on a pre-defined assessment scale. The latter is usually qualitative, ranging for example from "low" to "high" ESG performance or from "high" to "low" ESG risk. Recently, ESG aspects have started to be increasingly included in financial analysis and corporate valuation (Dorfleitner et al., 2015; Amel-Zadeh and Serafeim, 2018; Gibson and Krueger, 2018; Berg et al., 2019). ESG aspects represent additional criteria that investors may take into account next to the standard market criteria when allocating their investments. The ESG elements include for example the impact of a company on the environment (e.g. energy efficiency, waste disposal, GHG emissions etc.), the company's business relationships, the general working conditions within the company and its administration and direction (See Hyperlinks: UNEPFI Report; ESG Reports and Ratings Online Resource).

Similar to how credit ratings are used for traditional credit risk, ESG ratings are assigned to companies by rating agencies. These ratings have a relatively straightforward structure: for each component (environmental, social, governance), specific attributes are identified. For the environmental dimension these include, among others, company's environmental disclosure, impact and efforts to reduce carbon emissions. Hence, climate enters ESG indicators mostly through GHG emissions. The attributes characterizing each component are then evaluated by indicators, which allow to measure the attribute considered (for example, attribute E1 for the environmental dimension in Figure 4). Finally, a weight is assigned to each individual attribute reflecting its relative importance in the overall score (Berg et al., 2019).

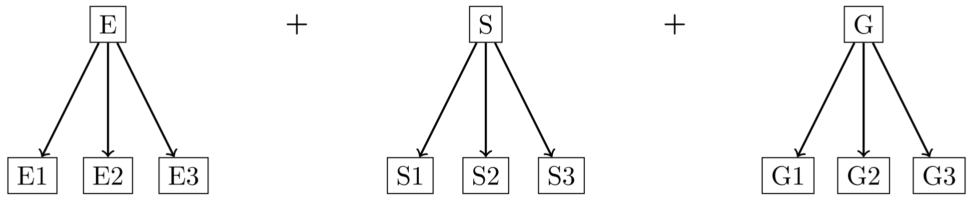


Figure 4: ESG structure example

Despite their common general structure, ESG ratings vary widely across rating agencies. Berg et al. (2019) show that the ESG ratings vary across different rating agencies and identify the sources of this divergence. In particular, they divide the overall divergence in scope (different sets of attributes as basis to form the ratings), weight (different views on the relative importance of attributes) and measurement (different indicators used to measure the same attribute).

# 3 Methodology

This study employs a quantitative meta-study approach to analyses a sample of transition-related climate risk assessment tools. In the following, we describe the study sample, the information collection via a structured questionnaire, and the analysis approach.

## 3.1 Study sample

The study aimed to cover a representative range of climate risk tools. To this end, 20 tool providers from financial services sector, think tanks and academia were asked to participate in the study. They have been selected based on the following three criteria: 1. Focus on climate-related transition risks; 2. Potential applicability for financial decision-making; 3. Distinctive interesting features to inform next steps and improve tool usage (e.g. exceptional depth of analysis, especially sound scenario-analysis approach, considerably wide range of financial applicability). Of these 20 tool providers, 15 providers participated in the study and 16 tools have been analysed (cf. Table 2). The majority of tools uses a fundamentals-based risk and valuation approach, based on scenario-analysis and sometimes also forward-looking projected emissions data. One tool employs a market-based approach, meaning that it assesses the implicit climate risk premium as prevalent in markets today, based on current emission and other data (financial market data). It is hence only forward-looking to the extent that financial markets are forward-looking, i.e. price-in future climate risks. The results of market-based tools therefore also depend on the extent to which fundamentals-based approaches are taken up by financial markets.

Three of the analysed tools were no distinct climate risk tools, but were mainly designed to perform climate impact analysis, climate alignment assessment or climate target setting. These tools were included as representative examples of their class to analyse to which extent and in which dimensions these tools differ from traditional risk tools. Moreover, these tools are sometimes mentioned in the risk analysis context, and their output could be used to inform climate risk assessments. It is hence important to include the assessment of their setup, usefulness and limitations in the climate risk analysis context. Yet, since the non-risk tools were not necessarily designed for risk analysis, the coverage, output and criteria assessments are not always fully applicable. This will be taken into account in the analysis.

| Provider | Tool name | Shortname | Type | Sector |
|---|---|---|---|---|
| 2 Degrees Investing Initiative | PACTA | 2DII | alignment/risk | think tank |
| Battiston, Monasterolo and Mandel | CLIMAFIN | CFIN | risk | academia |
| Cambridge Econometrics | E3ME-FTT-GENIE | CAME | risk | academia |
| Cambridge Institute for Sustainability Leadership | ClimateWise | CISL | risk | academia |
| Carbone 4 | Carbon Impact Analytics | CAR4 | impact | think tank |
| ISS ESG | Portfolio Climate Impact Report and Raw Data | ISSE | risk/impact | financial services |
| MSCI/Carbon Delta | Climate VaR | MSCI | risk | financial services |
| Oliver Wyman | Climate Transition Risk Methodology | OLWY | risk | financial services |
| Ortec Finance | ClimateMAPS | ORTE | risk | financial services |
| PwC/The CO-Firm | Climate Excellence | PWC | risk | financial services |
| right. based on science | XDC Model | RIGH | alignment/risk | think tank |
| Science-based targets initiative | SBT Tool and SDA Transport Tool | SBTI | target | think tank |
| S&P Global Market Intelligence | Climate Linked Credit Analytics | SPCM | risk | financial services |
| S&P Global Market Intelligence | Climate Linked Credit Risk Tool | SPPD | risk | financial services |
| University of Augsburg | CARIMA | UNIA | risk | academia |
| Vivid economics | Climate Risk Toolkit | VIVE | risk | financial services |

Table 2: Study sample

### 3.2 Information collection

Most information required for the analysis is not publicly available. Thus, we designed an extensive structured questionnaire, to gather the relevant information, and to encourage tool providers to be more transparent about the main mechanisms underlying their tools. The full questionnaire is documented in Appendix B. To encourage information provision, transparency credits were obtained in the analysis if all three parts of the questionnaire were answered (cf. criterion 1b)). Since we relied primarily on tool providers' self-disclosed information, a limitation of this study is that information about tool methods, which are not published in detail in academic journals, have not undergone a scientific peer-review process and might therefore be less reliable. This shortcoming is addressed in the analysis criteria (cf. Table 3). Results might suffer from overstatements, since tools had the incentive to be overly positive in their answers, given that their analysis results and the general setup would be individually reported to ease the tool selection for potential future tool users. We tried to limit this shortcoming and cross-checked the self-reported information, where possible. Information sources were webpage descriptions, tool white papers, tool application reports, academic publications, and additional personal conversations with tool providers.

### 3.3 Analysis approach

Our meta analysis is articulated along two main levels: First, a descriptive analysis focusing on the characteristics of the tools considered. These include coverage, which in turn refers to the risk sources and realisation and financial assets coverage, climate scenarios and climate-adjusted financial metrics. Second, a criteria-based analysis, which covers three different dimensions along with the performance of the indicators is assessed. These dimensions include accountability, depth of risk analysis and usability. In addition, we analyse further use cases, namely physical risks and climate targets, for reasons of completeness. Figure 5 provides a schematic visualization of the analysis approach adopted. In sum, our analysis approach is - to the best of our knowledge - the most comprehensive and in-depth analysis of climate transition risk tools for financial decision-making. In what follows, the three levels of analysis are described more in detail.

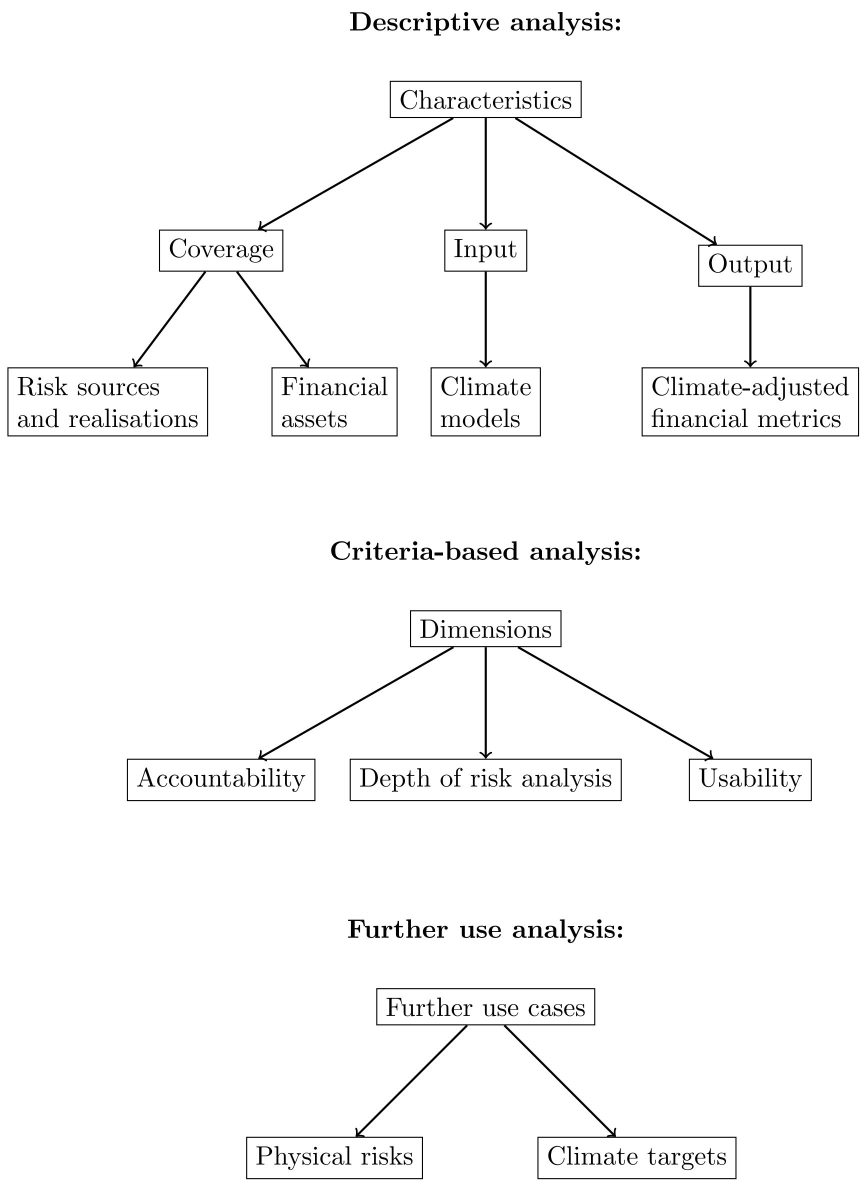


Figure 5: Analysis approach overview

**Descriptive analysis** In our descriptive analysis, we focus on three characteristics of tools: (1) The risk sources and realisations, and financial asset covered; (2) the climate scenarios used as input; (3) the climate-adjusted financial metrics produced as output. When considering the sources of risk, we include policy, market upstream (supply chain), market downstream (demand) and technology risks, which can materialise smoothly or in the form of a shock. Tools can cover individual financial assets (e.g. bonds, loans and credits) or aggregated financial assets (e.g. portfolios and funds). The climate scenarios and underlying assumptions adopted by each tool are relevant for our descriptive analysis as they have a remarkable impact on the outcome of the tools. Finally, the climate-adjusted financial metrics can be grouped in firm valuation metrics (e.g. market cap), financial asset risk/valuation metrics (e.g. Sharpe ratio and value at risk) and credit risk metrics (e.g. probability of default and credit rating). The descriptive analysis can be used as a first starting point by practitioners, academics and supervisory or regulatory authorities to understand the general setup, coverage and modules of individual climate risk assessment tools currently available. Moreover, it could guide tool users in their tool selection process. The descriptive characteristics analysis is also of high relevance to supervisory authorities and regulators: It identifies in which financial areas climate risk analysis is relatively readily available, and where tools and methods still need to be developed. Supervisory authorities can thereby identify potential blind spots, and support the development of the required methods.

**Criteria-based analysis** The criteria-based analysis is grouped along three dimensions: accountability, depth of risk analysis, and usability. The dimensions are assessed by aid of specific analysis criteria. It is important to note that any tool setup decision implies a trade-off between various criteria. Therefore, this study has not been designed to rank the various tools along the criteria. We rather aim to identify the state of the art and gaps through a meta analysis.[16] The performance of the tools against each criterion is assessed by aid of criteria-specific elements, as described in Section 4. For each tool, we examine whether the criterion is (mostly) fulfilled, partly fulfilled or not fulfilled, based on an in-depth evaluation of various elements, by criterion. Some aspects can be fulfilled on a customized basis only. This might improve flexibility, but at the same time could reduce model output comparability across different tools and might impair model transparency and the critical assessment of the overall model setup.

In order to aggregate the individual tool assessments for the criteria-based meta analysis, we assign 1 point for each fulfilled element, 0.5 points for partly fulfilled or customized approaches, and 0 points for not fulfilled or not applicable. The element assessment points are then summed up to obtain the overall score for a criterion. Based on the maximum obtainable points per criterion (which is $N_i$, with $N =$ the number of elements for criterion $i$), we define a criterion as fulfilled if more than 75% of the maximum points are achieved, as partially fulfilled if between 25% and 75% of the maximum score is achieved, and as not fulfilled for less than 25% of maximum obtainable criterion points. We use these results to count the amount of tools that fulfil, partially fulfil or do not fulfil the criterion, and report the numbers in the Section 5, by criterion and elements. For the dimensions meta analysis, we sum up the dimensions' respective criteria points, and assign the values "high" ( more than 75% of maximum obtainable points), "Medium" (25%-75% of maximum obtainable points) and "Low" (below 25% of maximum obtainable points). As before, we count the amount of tools for each of the values, and the results are reported in the Section 5.

**Further use analysis** In addition to the core analysis, the further use cases analysis reports whether tools are capable to account for physical risks and to analyse how financial decisions perform against the climate targets. With regards to physical risks, the study assesses whether these are covered in the standard tool output, and whether the trade-off between physical and transition risks is considered. With regards to the climate targets, we report whether the tool enables to assess targets alignment for financial institutions, and whether it claims that it is capable to measure the (positive) climate impact of financial institutions.[17] Whether and how the latter

[16] The individual tool results are reported for reasons of transparency, and to enable informed tool selection decisions for potential users.

[17] A (positive) climate impact analysis is the assessment to which extent the institution actively contributes to reducing real carbon emissions. Or, in other words, which impact the institution has on achieving a specific

is possible at all is currently extremely debated, for example in the context of the science-based targets for financial institutions methodology development.

# 4 Analysis criteria

The core of this study is a criteria-based analysis of the various tools. The contribution of this approach is threefold: First, we identify a set of important criteria, that tools would ideally fulfil to provide meaningful results. This set of criteria could constitute the first step towards developing a comprehensive theory of climate-related financial risk assessment approaches. The criteria could also inform regulatory authorities to define common principles for meaningful climate transition risk analysis for financial institutions. Second, we assess how the study sample performs against these criteria. This serves to display the status quo of climate risk tools, and identify key areas where tools need to be improved. Third, the results of the criteria-based tool analysis can be used to derive core best practice principles for tool users, tool providers and regulatory authorities.

Based on the literature and discussions with members from the advisory board, we identified three key dimensions for the criteria-based analysis: Accountability, depth of risk analysis, and usability. The following Sections describe the specific assessment criteria and their associated analysis elements for each of the three dimensions.

## 4.1 Accountability

Accountability ensures that the data input, the tool setup and the output are verifiable and can be critically evaluated by users and external experts in the field. It covers three criteria: Public transparency, emission data strategy, and science-based approach. The individual criteria are assessed by aid of various elements. These have been derived based on considerations in the literature, and conversations with the advisory board members. We use specific assessment rules to assess to which extent each tool fulfils which element, as reported in Table 3.

**1. Public transparency** is given by publicly available model modules and model code. Furthermore, we also report to which extent the participating tools answered the study questionnaire. This serves to highlight that tools undertook an important step towards increasing public transparency by participating in this study. Yet, since the questionnaire information is still not entirely publicly available, this element will not enter the meta analysis of the transparency criterion in the accountability results Section 5.2.1.

**2. Emission data** are a key driving input across all models. Reliable emission data might be difficult to obtain. Hence, a transparent and careful emission data strategy is another important feature of accountability. We check whether data sources are reported, whether data are third party verified (since emission data databases often use self-reported data, which is less reliable), and how the tool providers deal with missing data. Last, we also assess whether tool providers follow a science-based approach.

climate target. This climate impact analysis is different from the alignment analysis, since alignment can include the restructuring of the portfolio, which would reduce climate risk exposure of the institution, but not necessarily result in less carbon emissions in the real economy. In contrast, the climate impact analysis should focus on exactly this real effect.

| I. ACCOUNTABILITY | | |
|---|---|---|
| Assessment criteria and elements | | Assessment rule |
| **1. Public transparency** | | |
| a) Model modules and code publicly available | x | Fulfilled: Full model description and code generally public |
| | (x) | Partially fulfilled: Very detailed model modules documentation publicly available, code generally available for research institutions |
| | - | Not fulfilled: Model modules and code generally not public |
| b) Study questionnaire* | x | Fulfilled: Fully completed the questionnaire for this study |
| | (x) | Partially fulfilled: Completed most parts of the questionnaire |
| | - | Not fulfilled: Did not fill-in the questionnaire. In this case, the tool is not included in the report |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Fulfilled: Data source fully reported |
| | (x) | Partially fulfilled: Data sources partly reported, sources are missing |
| | - | Not fulfilled: Data sources not reported |
| b) Third party verified | x | Fulfilled: Emission data are third party verified |
| | (x) | Partially fulfilled: Emission data from own calculations or own data accuracy tests |
| | - | Not fulfilled: Emission data self-reported or from databases without third party verification (database provider's own calculations or database uses self-reported data) |
| c) Missing data strategy | x | Fulfilled: Missing data strategy is explained, at least for emission data |
| | (x) | Partially fulfilled: Missing data strategy in place, but not explained, at least for emission data |
| | - | Not fulfilled: Unclear how providers deal with missing (emission) data |
| **3. Science-based approach** | | |
| a) Scientific references | x | Fulfilled: Model modules and climate scenarios explicitly build on approaches published in scientific research and provider justifies the approach with scientific references |
| | (x) | Partially fulfilled: Climate scenarios are used from climate science, but other model modules do not explicitly build on scientific approaches. This also includes the IEA scenario family, since the IEA is a political organisation. |
| | - | Not fulfilled: Neither climate scenarios, nor model modules are explicitly based on scientific research. |
| b) Peer-reviewed | x | Fulfilled: Tool method published in an academic journal and has been peer-reviewed in an independent / anonymous review process |
| | (x) | Partially fulfilled: Tool documented in scientific working paper to enable comments and exchange amongst scientists, or academic institutions involved in tool setup |
| | - | Not fulfilled: Not scientifically published and peer reviewed |

*) Documented in the results, but does not count into the meta analysis.

Table 3: Accountability criteria

**3. Scientific references** should ensure that tools' approaches are scientifically justified. This criterion is important, since some tool providers officially claim to be "science-based". Yet, it has been recently criticised that climate risk and alignment tools seem to be more "an art than a science" (Institut Louis Bachelier, 2020). To mitigate this criticism, tools should build on relevant science and build on peer-reviewed models and considerations. Ideally, tools are themselves peer-reviewed. This ensures that the approach has been critically evaluated and commented by independent academics with field knowledge. It is an important complement to public transparency of the model modules and the code.

## 4.2 Depth of risk analysis

An assessment of the depth of risk analysis is important for two main reasons. First, understanding the depth of risk analysis of tools is crucial to correctly interpret their output. For example, GHG emissions are widely used as risk exposure indicators. But they should not be confounded with a full risk indicator, since they only cover one (static) aspect of risk. Second, the depth of risk analysis serves to identify where tools need to improve furtehr to adequately assess climate-

| II. DEPTH OF RISK ANALYSIS | | |
|---|---|---|
| Assessment criteria and elements | | Assessment rule |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Fulfilled: 1.5/<2°C scenario part of default / standard exposure analysis |
| | (x) | Partially fulfilled: not used, since no meaningful assessment category for this element |
| | (c) | Only customized: 1.5/<2°C scenario analysis could only be considered in customized approach |
| | - | Not fulfilled: 1.5/<2°C scenario analysis not considered |
| b) Country-differentiated | x | Fulfilled: Hazard differentiated by countries or other jurisdictional entities in default setting |
| | (x) | Partially fulfilled: Hazard differentiated by world regions |
| | (c) | Only customized: Hazard differentiated by countries (or regions) in customized approach, only |
| | - | Not fulfilled: Hazard not differentiated by countries (or regions) |
| c) Sector-differentiated | x | Fulfilled: Hazard differentiated by sectors or other economic entities in default setting |
| | (x) | Partially fulfilled: Hazard differentiated by sectoral categories like e.g. real economy versus financial sector, or energy intensive sectors versus service sectors |
| | (c) | Only customized: Hazard differentiated by sectors in customized approach, only |
| | - | Not fulfilled: Hazard not differentiated by sectors |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Fulfilled: All GHG emissions at scope 1-3 covered or explicit materiality analysis to cover most important GHG emissions in exposure analysis |
| | (x) | Partially fulfilled: Covers all scopes but only few GHG emission types or many GHG emission types but not all scopes |
| | (c) | Only customized: GHG emissions not considered, can be included in customized analysis |
| | - | Not fulfilled: GHG emissions not considered at all |
| b) Expected GHG emissions | x | Fulfilled: Capital lock-in (capital lifetime) or CAPEX emission intensity are considered |
| | (x) | Partially fulfilled: Capital lock-ins or CAPEX are indirectly considered |
| | (c) | Only customized: Capital lock-ins or CAPEX can only be considered in customized analysis |
| | - | Not fulfilled: Capital lock-ins or CAPEX are not considered |

Table 4: Depth of risk analysis criteria (1/3)

related transition risks. If the climate risk data used for financial decision-making or micro- and macroprudential financial supervision build on output from tools with incomplete risk analyses, users and authorities might struggle to correctly deal with the risks.[18]

The IPCC states in the 5th Assessment report that climate disaster risk is determined by a combination of exposure, vulnerability and hazard. This approach to climate risk assessments is useful for financial climate risks, too. Often, economic and financial climate risk analyses only assess the exposure of a specific economic entity to climate-related hazards. However, vulnerability, resilience and adaptability to climate-related developments, and the realised economic impact for the risk materialisation case need to be equally taken into account (IPCC, 2014; Bresch et al., 2014). Monnin (2018b) confirms this consideration. He states that it is important to include the ability of the specific firm to pass the change in costs on to consumers, as this could significantly reduce the economic impact for the firm, and the readiness of the firm to the transition, as captured for instance by the the CAPEX planned in low-carbon technologies in climate-related financial risk assessments. Building on these considerations, we draw on insights from climate science, economic theory, and finance to define the criteria for the depth of risk analysis. The list reflects the notion of climate risks as defined in (IPCC, 2014), and has been adapted for the purpose and scope of this

[18]Whilst our analysis provides a first starting point to assess the depth of risk analysis of various tools, it is important to note that we do not perform a quality assessment of how well the individual risk aspects are captured. Various stakeholders expressed concerns that, for example, input substitution and cost pass-through need to be very carefully modelled to provide decision-relevant results for confident usability.

| II. DEPTH OF RISK ANALYSIS (2/3) | | |
|---|---|---|
| Assessment criteria and elements | | Assessment rule |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | x | Fulfilled: The amount of profits to cover potential transition-induced additional costs is considered |
| | (x) | Partially fulfilled: The amount of profits to cover potential additional costs is only indirectly or else considered |
| | (c) | Only customized: The amount of profits to cover potential additional costs can only be considered in customized analysis |
| | - | Not fulfilled: The amount of profits to cover potential additional costs is not considered |
| b) Peers performance, competition | x | Fulfilled: The performance relative to competitors and peers are considered |
| | (x) | Partially fulfilled: The performance relative to competitors and peers is indirectly considered |
| | (c) | Only customized: The performance relative to competitors and peers can only be considered |
| | - | Not fulfilled: The performance relative to competitors and peers is not considered |
| c) Cost pass-through | x | Fulfilled: The ability to pass on additional costs to consumers is considered |
| | (x) | Partially fulfilled: The ability to pass on additional costs to consumers is only indirectly or else considered |
| | (c) | Only customized: The ability to pass on additional costs to consumers can only be considered in customized analysis |
| | - | Not fulfilled: The ability to pass on additional costs to consumers is not considered |
| **7. Adaptability** | | |
| a) Input substitution | x | Fulfilled: Input substitution possibilities to reduce production costs are considered |
| | (x) | Partially fulfilled: Input substitution possibilities to reduce production costs are only indirectly or else considered |
| | (c) | Only customized: Input substitution possibilities to reduce production costs can only be considered in customized analysis |
| | - | Not fulfilled: Input substitution possibilities to reduce production costs are are not considered |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Fulfilled: Climate strategy, climate-aligned R&D or future CAPEX plans and the associated impact on future exposure and vulnerability are considered |
| | (x) | Partially fulfilled: Climate strategy, climate-aligned R&D or future CAPEX plans and the associated impact on future exposure and vulnerability are only indirectly or else considered |
| | (c) | Only customized: Climate strategy, climate-aligned R&D or future CAPEX plans and the associated impact on future exposure and vulnerability can only be considered in customized analysis |
| | - | Not fulfilled: Climate strategy, climate-aligned R&D or future CAPEX plans and the associated impact on future exposure and vulnerability are not considered |

Table 5: Depth of risk analysis criteria (2/3)

study. We draw on standard considerations from microeconomic theory and macroeconomic theory, and selected research on the impact of transition shocks and smooth transition developments on economic activity, financial risk, and financial networks. In line with the risk aspects, we identified 6 important depth of risk criteria: hazard, exposure, vulnerability and resilience, adaptability, economic impact, and risk amplification mechanisms. Each of the criteria will be explained in the following paragraphs. The rules to assess to which extent each tool fulfils which element of the depth of risk analysis criteria are reported in Tables 4, 5 and 6.

**4. Hazard** is, for the purpose of this study, defined as a potential transition risk source (e.g. policy, market upstream, market downstream, technology) and its associated realisation (shock and/or smooth). The transition risk sources and realisations are usually modelled by aid of climate scenarios. Temperature targets have important implications on the possible realisation of transition risk sources, and the lower the temperature target, the more intense and more probable would be the potential hazard. Although most tools cover at least a 2°C scenario, it is important that hazard is reflected by using 1.5/<2°C scenarios. There are significant differences on the scale and

| II. DEPTH OF RISK ANALYSIS (3/3) | | |
|---|---|---|
| Assessment criteria and elements | | Assessment rule |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Fulfilled: Various transition-induced economic loss and gains channels are considered in the economic impact assessment. Channels could include: A) Change of profits; B) Change of revenues based on (a) change of demand, (b) change of wholesale price, (c) other; C) Change of production costs based on (a) change of input prices, (b) change of production technology-related fix costs, (c) change of production technology-related variable costs, (d) other |
| | (x) | Partially fulfilled: Economic loss and gains channels are partly considered, or economic losses and gains are only indirectly considered in the economic impact assessment |
| | (c) | Only customized: Economic losses and gains can only be considered in customized analysis in the economic impact assessment |
| | - | Not fulfilled: Economic losses and gains are not considered in the economic impact assessment |
| b) Macroeconomic development | x | Fulfilled: Macroeconomic aspects like transition-related changes in within-sector competition, an economy's overall sectoral composition, or changes in trade patterns are considered in the economic impact assessment |
| | (x) | Partially fulfilled: Macroeconomic aspects are only partially or only indirectly considered in the economic impact assessment |
| | (c) | Only customized: Macroeconomic aspects can only be considered in customized analysis in the economic impact assessment |
| | - | Not fulfilled: Macroeconomic aspects are not considered in the economic impact assessment |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | x | Fulfilled: Mutual risk amplification effects are considered in the economic impact assessment. An example for such an effect: technological developments make more stringent climate policy more feasible and hence more likely. |
| | (x) | Partially fulfilled: Mutual risk amplification effects are only indirectly or else considered in the economic impact assessment |
| | (c) | Only customized: Mutual risk amplification effects can only be considered in customized analysis in the economic impact assessment |
| | - | Not fulfilled: Mutual risk amplification effects are not considered in the economic impact assessment |
| b) Financial market amplification | x | Fulfilled: The financial risk assessment also considers financial market amplification mechanisms (e.g. network effects, sentiment and expectations revisions, balance sheet effects) |
| | (x) | Partially fulfilled: The financial risk assessment partially or indirectly considers financial market amplification mechanisms |
| | (c) | Only customized: Financial market amplification mechanisms can only be considered for financial risk assessment in customized approach |
| | - | Not fulfilled: The financial risk assessment does not consider financial market amplification mechanisms |

Table 6: Depth of risk analysis criteria (3/3)

speed of emission reduction requirements between 2°C and 1.5/<2°C, which have an impact on the probability and intensity of potential hazards (i.e. transition-related developments or shocks). For example, emissions from fossil fuels and industry need to be close to zero by 2050 for most 1.5°C pathways, 20 years earlier than projected in many 2°C pathways (Rogelj et al., 2018). Furthermore, as discussed in Section 2.1, hazards could differ between countries (e.g. policy and market up- or downstream risks) and sectors (e.g. technology and market up- or downstream risks). Differentiating potential hazards by countries and sectors provides, ceteris paribus, potentially more realistic results. For example, most climate policies currently differ across sectors. This is even true for carbon pricing schemes. Modelling a global uniform carbon price as policy risk might be a first starting point for the risk assessment. However, without country- and sectoral-differentiation, the risk analysis could potentially be misleading.[19]

[19]Note also that it is important to focus on future expected climate policies for financial risk assessments, since existing climate policies should already be priced-in by the market. Current climate policies can be used as a scenario starting point, or to define the business as usual scenario (if it is assumed that future climate policies as defined in the NDCs will not be implemented).

**5. Exposure** in the present context is mainly determined by future GHG emissions. Status quo or backward-looking data are of limited use to assess transition risks (Chenet et al., 2019; Battiston et al., 2017). Ideally, tools would use forward-looking emission data for all material scopes and types of emissions, based on individual emission type and scope materiality assessments by use case. This would mean models should ideally not only cover Carbon Dioxide, but also important further emissions like Methane emissions from the agricultural, waste management and Oil & Gas sector. However, acknowledging data issues in this context, we assess exposure coverage as a combination of current GHG emissions, and future expected GHG emissions. Current GHG emission data covering the relevant scopes and types is easier to obtain than forward-looking expected GHG emissions. Furthermore, they provide the starting point for the analysis. Expected GHG emissions can be approximated by taking the capital stock's emission intensity and remaining lifetime into account. This involves modelling exercises and assumptions on future economic activities. The higher the scopes, the higher the risks for less reliable data and double counting. Even more so for expected GHG emissions. This might imply a trade-off between coverage and quality. If a tool provider wants to ensure high quality emission data, covering scope 3 emissions might be a challenge.[20]

**6. Vulnerability and resilience** determine how severe a hazard could impact the unit of analysis. For the present study, three elements from microeconomic theory are used to evaluate whether and how vulnerability and resilience are taken into account by the tools. The three elements are profits to cover costs, peers performance and competition, and cost pass-through (Lise et al., 2010; Sijm et al., 2012; Fabra and Reguant, 2014; de Bruyn et al., 2015; Hintermann, 2016; Batten et al., 2020). A business unit with higher profits should, ceteris paribus, be more resilient and hence less vulnerable than a unit with only few surplus. Profits could serve as a buffer to deal with the smooth transition or shocks, to pay potential additional costs to stay in the market, or to stay profitable even with lower revenues. The amount of profits has also a direct link to expected dividend payoffs, and is hence especially relevant for financial risk and valuation analyses. Furthermore, a business entity facing low competition or where peers perform relatively worse is less likely to lose market shares given the transition developments or shocks. The latter also influences the ability of a business unit to pass on any potential additional costs to consumers without risking a significant drop in demand due to the higher prices.

**7. Adaptability** is the capability of the unit under analysis to actively adapt to smooth transition developments over time or to undertake measures, which reduce the impact of potential shocks. Two elements feature the adaptability assessment in the present case: Input substitution, and climate strategy, climate-aligned R&D or future CAPEX plans. Both elements are closely linked to production technology and production processes (scope 1 and scope 2), as well as market upstream emissions (scope 3). In addition, R&D spending could target market downstream emissions (scope 3). If tools consider companies' climate strategies in the assessment of adaptability, it is important to note that there is a risk that the climate strategies are publicly announced, but not implemented. Furthermore, the presence of a strategy does not mean that it is sufficient in scope and scale to be aligned with the climate targets or to effectively reduce climate transition risks. Tangible metrics like future-related current expenditures (CAPEX plans and R&D investments) might be more reliable.

[20]Emission data quality is assessed in the data strategy criterion, cf. Table 3

**8. Impact** is determined by the interplay between hazard, exposure, vulnerability and resilience, and adaptability. An assessment of climate-adjusted financial transition risks needs to quantify the economic impact on the underlying unit of analysis. It consists of direct economic losses and gains; and indirect effects via changes in the macroeconomic development. Economic losses (gains) include, among others, transition-induced negative (positive) changes in profits, revenues, and positive (negative) change in production costs, which affect the cash-flow of the individual company. With the macroeconomic development element, the study assesses whether a tool accounts for changes in the macroeconomic structure due to the transition risk. Macroeconomic changes are mainly transition-induced changes of the local or global economic performance (e.g. GDP growth), sectoral composition or changing trade patterns (Gros et al., 2016; Bretschger and Soretz, 2018; Bretschger and Karydas, 2019; Semieniuk et al., 2020; Liu et al., 2020). Second round effects could exacerbate the impact of the initial shocks.

**9. Risk amplification mechanisms** could severely exacerbate the impact of an initial transition development or transition shock. The realisation of one risk source could also trigger further adverse events and developments (Brausmann et al., 2020). These amplification mechanisms are very important for financial supervision, but also for individual investors. In the context of the present analysis, we identified two main sources for risk amplification mechanisms: The dynamics inherent to economic transitions, and the financial market's interconnectedness. First, due to the dynamic interplay between economic policy, market and technological developments, any climate-related transition risk could be amplified in speed of emergence and in scale by any other climate-related transition shock or development (Bretschger and Karydas, 2019). For example, climate policy might speed up technological developments, which in turn increases the risk and adverse economic impact of disruptive technology breakthroughs on non-anticipating actors or on technology adoption laggard firms. Second, financial market-related risk amplification channels could severely exacerbate the impact of an initial transition development or transition shock, via network effects and second round balance sheet effects, or sentiment and expectation revisions in the presence of herding behaviour (Battiston et al., 2017; Dunz et al., 2018; Stolbova et al., 2018; Vermeulen et al., 2019; Roncoroni et al., 2019; Campiglio et al., 2019). As such, Carney et al. (2019) warned of the potential for a transition-driven "Minsky moment", whereby a disorderly transition leads to a sudden collapse in asset prices. This situation has been defined as the risk of a "Green Swan" (Bolton et al., 2020). It is important to improve the understanding and analytical capabilities to analyse such systemic climate-related risks, given that the realisation of these systemic risks is considered to be more likely when the source of risk is not well understood (Eis et al., 2020).

## 4.3 Usability

Climate transition risk tools for financial decision-making are usually explicitly designed to be applied in practice. Hence, usability is of high importance. Due to the special structure of most tools, and the peculiar characteristics of transition risks, output interpretability and how tools deal with uncertainty are very important criteria in this regard.[21] The rules to assess to which extent each tool fulfils which element of the depth of risk analysis criteria are reported in Table 7.

[21] In addition to these two criteria, it is important for usability that tools provide financial decision-making relevant metrics. However, it very much depends on the use case which financial risk metric would be appropriate. Furthermore, tool providers face the trade-off between broad risk metrics coverage, and targeted single metric

| III. USABILITY | | |
|---|---|---|
| Assessment criteria and elements | | Assessment rule |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Fulfilled: Scenarios and key assumptions explicitly stated |
| | (x) | Partially fulfilled: Scenarios explicitly stated, but not key assumptions |
| | - | Not fulfilled: Underlying scenarios and assumptions not explicitly stated |
| b) Assumptions-based output communication | x | Fulfilled: Key scenario- and tool assumptions and limitations are re-stated in direct connection to the tool output, for example in a sentence like "assuming A,B,C for the underlying scenario, and DEF for the further analysis modules, whilst disregarding D,E,F, the climate-adjusted VaR for company NAME is 000" |
| | (x) | Partially fulfilled: Some key tool modules assumptions are reported next to the output, but underlying scenario assumptions are not explicitly stated, and/or key limitations of the analysis are not stated in direct connection to the tool output |
| | (c) | Only customized: Key scenario- and tool assumptions and limitations can be re-stated in direct connection to the tool output in a standardised sentence, if the client asks for it |
| | - | Not fulfilled: Even if assumptions and limitations are in general reported (see element 10a), these are not re-stated in a standardised format in direct connection to the tool output |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | Fulfilled: The tool's baseline / business-as-usual-approach is fully flexible with regards to assumptions and scenarios |
| | (x) | Partially fulfilled: Users have a pre-defined set of options to choose from to set the tool's baseline |
| | (c) | Only customized: The baseline can be adapted in customized approach, only |
| | - | Not fulfilled: The baseline is fixed and scenarios or assumptions cannot be adapted |
| b) Scenario-neutral (various risk realisations) | x | Fulfilled: The tool's transition development assumptions and scenarios or fully flexible (scenario-neutral tool) |
| | (x) | Partially fulfilled: Users have a pre-defined set of options to choose from to define the tool's transition assumptions and/or scenarios |
| | (c) | Only customized: Transition assumptions and/or scenarios can be adapted in customized approach, only |
| | - | Not fulfilled: The transition assumptions or scenarios employed by the tool are fixed and cannot be adapted |
| c) Probability distribution input (transition risk timing) | x | Fulfilled: The points in time when the considered risk source(s) realise(s) are modelled by aid of a probability distribution of the likelihood of the risk occurring over a certain timeframe |
| | (x) | Partially fulfilled: The point in time when the considered risk source(s) realise(s) is explicit and timing can be flexibly adapted or chosen from a set of various points in time, and/or a stochastic modelling approach is available to reflect uncertainty in the model |
| | (c) | Only customized: The point in time when the considered risk source(s) realise(s) is explicit but can only be adapted in customized approach |
| | - | Not fulfilled: The risk realisation timing is explicit but not adaptable or neither explicit nor adaptable |
| d) Probability distribution output (financial risk values) | x | Fulfilled: The tool by default provides a probability distribution of possible output values, generated by using various transition scenarios, climate targets and assumptions |
| | (x) | Partially fulfilled: Various output realisations are otherwise reflected in the tool output |
| | (c) | Only customized: Users can run the tool multiple times with various assumptions and model calibrations to generate a probability distribution of the tool outputs (but tool output itself not based on a probability distribution that is generated within the standard modelling process) |
| | - | Not fulfilled: Uncertainty and the range of possible outcomes are not explicitly part of the tool output or otherwise reflected |

Table 7: Usability criteria

coverage. The appropriate tool depends on the use case. We therefore report the financial metric coverage in the descriptive analysis in Section 5, and do not feature the financial metrics coverage in the criteria-based analysis.

**10. Interpretability** of the tool output is an important criterion for usability. Since the tool output is usually a figure, assumptions and drivers are easily hidden in a single number. However, these could have a significant impact on the final output. The output interpretability criterion thus assesses whether the model structure, key drivers, and assumptions are well reported by tool providers, and whether the tool output itself is communicated in direct relation to key assumptions and model limitations. This is important for tool users and other users of the tool output (like investors or supervisory authorities) to better understand what is actually measured by the tool, and what the output really tells.

**11. Dealing with uncertainty** is a key criterion for any future-related analysis. Climate-related transition risks represent an exceptional challenge in this regard. It is extremely hard to identify an appropriate probability distribution capturing when a certain shock might occur, or a smooth transition event might start; and how intense it will be. Climate transition risk realisations (i.e. their timing and scale) do not follow the standard normal probability distribution. Fat tails do not only hold for physical climate risks (Weitzman, 2011) - Thomä and Chenet (2017) argue that they might also apply to climate transition risks. In addition, as stated in Chenet et al. (2019); Battiston et al. (2019); Bolton et al. (2020), climate risks are characterised by deep uncertainty, non-linearity, path dependency, non-stationary distributions over time, endogeneity. These aspects have been highlighted in the recent literature: For example, Bretschger and Soretz (2018) analyse the effect of uncertain environmental policies, which follow a Poisson process, on investment decisions and their macroeconomic consequences. Karydas and Xepapadeas (2019b) model financial climate risks in a CAPM with stochastic probabilities. Based on these considerations, the uncertainty criterion captures four elements. The first two elements relate to whether tools are able to accommodate users' individual expectations and beliefs about baseline developments and future transition pathways. The other two elements relate to the uncertain nature of transition risk realisations (tool input) and how they translate into financial risks (tool output). Both are ideally captured by a probability distribution-based approach.[22] As an alternative to the probability distributions of inputs and outputs, tools could also be run several times with varying assumptions about the timing and scale of the transition risk realisation. This would generate a probability distribution of various output realisations, based on different assumptions. However, the input assumptions should then also be justified by aid of probability distribution considerations.

# 5 Results

Climate risk assessments are a dynamically evolving field. This study aims to contribute to improve the tools available. The results of the analysis are a snapshot of the status quo, but tools are likely to be further developed in the future. The study will summarise key findings with regards to how the tools in general perform against the previously defined criteria. This serves to identify most advanced areas, and key gaps amongst existing tools. The Tables with the detailed results by tool provide an overview of tools' coverage, setup, output and performance against key criteria. When reading the Tables, it is important to note that some tools might not cover many aspects or fulfil

[22]The tool input, namely the occurrence of transition risks (i.e. their timing) is ideally captured by an appropriate probability distribution of the transition shock occurring, or of the transition development starting point and speed. Note that in addition to the risk timing probability distribution, the shock or development scale (e.g. various carbon pricing realisations) would ideally also be captured by aid of an appropriate probability distribution.

many criteria, but they might still have an interesting and well-developed approach towards some key aspects of climate-related financial risk analysis. Furthermore, modelling decisions always imply trade-offs between the level of detail and the issues of feasibility, overfitting and coverage. This study therefore never intended to provide a ranking of "best" tools or compare the individual tools directly one to another. Given the variety of analysed aspects in this study, a ranking would not be meaningful, and not necessarily useful. Instead, this study aims to contribute to a better understanding of existing tools, and identify further areas of development. In the following, we report the results of our descriptive and criteria-based analysis in Sections 5.1 and 5.2. In addition, we report the applicability of the tools in our sample on further use cases in Section 5.3.

## 5.1 Descriptive analysis

### 5.1.1 Coverage: Risk sources and realisations

As can be seen in Table 8, 5 out of 16 tools cover all analysed risk sources and risk realisations as part of the standard setting. All tools considered cover at least one risk source, besides the target-setting tool, which does not capture risks. Most tools (11 out of 16) cover both smooth (orderly) and shock (disorderly) realisations of the risks. Considering the tools which only cover one type of policy risk realisation, one tool covers policy shocks, and three tools cover smooth developments. Thus overall, slightly more tools cover smooth realisations of policy risk, but the difference is marginal. Policy risk is covered, partially covered or available on a customized basis for all tools besides the target setting tool. It is usually modelled by aid of a carbon price. All other risk sources are covered by 13 out of the 16 tools. If a tool covers market upstream risks (supply chain-related risks), it also covers market downstream risks (demand-related risks). Demand-side management and mitigation options are projected to be increasingly important to achieve the $1.5/<2°C$ scenarios (Rogelj et al., 2018). Only two of the risk tools do not capture neither market risk in any realisation. Technology risks are captured by 13 tools. The impact tool, the target setting tool and one risk tool do not cover technology risks. In general, if a tool covers only few risk sources, it covers policy risks.

In sum, most important risk sources and realisations are relatively well covered across the tool sample. There exist multiple tools for each risk source and realisation. Multiple tools can be used to derive assessments for a single use case, which is useful to prevent reliance on a single tools' output when analysing risks. However, only five tools are capable to capture that transition risks are likely to stem from all the different sources at the same time. Furthermore, transition risk impacts likely mutually reinforce each other. For example, more stringent climate policies might induce technological change, which in turn could induce even more stringent climate policies if abatement technology becomes available, or its costs decrease due to economies of scale and learning effects (Brausmann et al., 2020). As a consequence, further tool developments would benefit from full risk source coverage, and caption of mutual reinforcing risk impacts.[23] Furthermore, more stringent and streamlined information for potential tool users and supervisory authorities about tools' specific risk sources and realisation coverage could be beneficial to ensure a correct interpretation of the tools' output.

[23]This aspect is further assessed in the criteria-based analysis (depth of risk assessment).

### 5.1.2 Coverage: Financial assets

The tools cover different asset classes, as can be seen in Table 9. A majority (9 out of 16) of tools covers more than five individual or aggregated assets. Portfolio analysis can be conducted by 11 of the 16 tools, funds are covered by 9 tools. With regards to individual assets, best coverage can be observed for corporate bonds and loans (12 out of 16 tools), as well as for stocks (11 out of 16 tools). This is likely due to the greater availability of data for publicly traded asset classes, compared to other asset types. With 8 out of 16 tools, half of the analysed tools cover government bonds.[24] Project loans and personal loans (credits) are covered each by 7 (mostly different) tool providers. Mortgages and real assets are covered by 5 and 6 tool providers, respectively. In addition, 2 tool providers are currently developing an approach to include this two asset classes. Options and derivatives can be covered by 4 providers, yet in two cases, on a customized basis, only. The limited coverage of options and derivatives is likely due to the additional level of complexity of their valuation. 2 tools do not cover any of the asset classes. One is the target setting tool, which is currently developing a method for target setting in financial institutions. The other is a more macroeconomic oriented tool, which focuses on aggregate changes in financial flows, given the transition.

In sum, publicly traded asset classes are well covered in the present tool sample, most likely thanks to data availability. Every asset class is covered by more than two tools. This allows tool users to compare the results of different tools, which represents an advantage compared to the case in which users must rely on a single tool's assessment. Tool providers should expand the analysis of mortgages and real assets, since they are very important in the context of capital lock-ins and real GHG emission effects. Furthermore, project loans could become increasingly important to finance investees' low-carbon investments and hence release transformative potential. This could also reduce the overall exposure of the investee, with a potential impact on all other asset classes' value. These findings are in line with recent recommendations from the Net-Zero Asset Owner Alliance (See Hyperlink NZAOA 2020). However, data availability is currently one of the main constraints to expand the coverage of tools in the key areas of mortgages, real assets and project loans. Developing the tools further thus also means to find solutions to the data challenge in this context.

### 5.1.3 Input: Climate transition scenarios

Climate models and transition scenarios are subject to change, reflecting developments in modelling possibilities but also changes in transition narratives. The following analysis therefore only represents the status quo. Given the ongoing activities in climate modelling research, models and scenarios which capture the trade-offs between physical and transition risks (like the NGFS reference scenarios), and more granular 1.5°C transition pathways, are likely to become available for climate risk analyses in the near future.

In the present analysis sample, the most widely referenced pathways for the transition risk analysis are the IEA scenarios and the PIK/IIASA IAM scenarios. In particular, 6 out of the 16 tools analyzed use one or more scenarios developed by the IEA (See Hyperlinks IEA World Energy Model, IEA Energy Technology Perspectives Online Documentation). A major reason for

[24] We included government bonds for completeness in this overview. However, the depth of risk analysis would have to consider different features than for corporate issuers. For example, fiscal sanity, macroeconomic outlook and country-level climate adaptation measures would be important aspects to take into account. Therefore, the criteria-based analysis only focuses on corporate issuers.

this result is that the IEA models currently provide the most granular global sector coverage. 6 tool providers are also able to develop own scenarios. 1 tool also uses the Greenpeace Energy [R]evolution scenario to compare pathways with the IEA scenarios. Another tool provides the standard option to use the Principles for Responsible Investment's Inevitable Policy Response project Forecast Policy Scenario (See Hyperlink PRI IPR FPS Online Documentation). On the IAM coverage, 4 tools use either the REMIND-MAgPIE scenarios from PIK and IIASA, or the MESSAGEix-GLOBIOM model. The REMIND-MAgPIE model has been used recently to model the NGFS reference scenario pathways. It is likely that the NGFS scenario narratives will be increasingly used in the future, since IIASA, PIK and others, together with the NGFS, launched an NGFS scenario database, to ease comparable climate risk analyses, as stated in section 2.1 (See Hyperlinks NGFS Scenarios Documentation, IIASA NGFS Scenario Explorer Database). The fact that tools use similar scenarios suggest that users could more easily compare the results of various tool outputs. In general, it is nevertheless important to note that all scenarios come at a shortcoming. The IEA scenarios, for example, systematically underestimated the growth of renewable energies, with the risk of introducing a bias in the analysis (Creutzig et al., 2017; Mohn, 2020). Furthermore, the IEA model transparency is low, which makes the critical review of the assumptions and modelling choices more difficult. Moreover, the IEA scenarios do not allow for a 1.5°C analysis at the common 66% likelihood level, and relies to relatively large extent on negative emission technologies (NETs). On the other hand, the limitations of IAMs have also been stressed in the literature (Pindyck, 2013, 2017). In general, IAMs are less granular than the IEA scenarios. This is why investors increasingly stress the need for more granular 1.5°C scenarios (See Hyperlink: NZAOA 2020). The call usually comes from the community of net-zero investors; however, it has also its relevance for risk assessments.

Own scenarios are used or can be used in customized setting in 6 out of the 16 tools. The advantage of own scenarios would be that users have more flexibility to adapt the scenarios to their own beliefs and expectations. However, this comes at a major disadvantage: The scenarios lack transparency, are usually not peer-reviewed and not critically discussed in the scientific community, and render the comparison of results across different tool providers much more difficult. Hence, they might perform well in terms of decision-relevance; however, quality and comparability of the tool output might be negatively affected.

Given these results, we find that scenario-neutral tools have major advantages. They would allow the users to run the analysis with multiple scenarios, from various model developers. This enables users to better capture the deep uncertainty surrounding future transition developments. Furthermore, in most cases, it would allow users to use the tool with scenarios reflecting the trade-off between physical and transition risks, and more granular 1.5°C scenarios, once they are available.

During the course of the analysis, we also realised that even tool providers sometimes struggle to state the key scenario assumptions. These include, for example, the temperature peak year, overshoot considerations (emissions or temperature), the use of NETs and CCS, the year of net-zero emissions at country, global, sector and firm-level, the energy mix in the target year, and others. However, these assumptions are key to interpret the tool output correctly and are very important for financial decision-making. As stated in section 2.1, given the same temperature target, the assumptions impact for example trade-offs on investment needs in specific technologies[25], influence whether and how early an asset might become stranded. Recent research on the risk of assets stranding calls for a precautionary assumptions approach, with early emission peaks, low reliance on NETs and low use of CCS (Chenet et al., 2019). If tool providers and tool users are not fully aware of the assumptions and their implications, they might select a less precautionary modelling approach, which might not be suitable for risk averse investors. This observation indicates that it would be important to report the tool output in direct connection to the key assumptions and modelling choices, as defined in criterion 10b (see Table 7 in section 4.3), and as recommended by NGFS (2020b). Furthermore, common guidelines on tool transparency would be useful, stating the key values (or range of values) for most important assumptions of the various scenarios employed by the tool.

#### 5.1.4 Output: Climate-adjusted financial metrics

The analysed tools provide various climate-adjusted financial risk and valuation metrics, as can be seen in Table 11. The impact, alignment and target setting tools were not necessarily designed to provide financial metrics as part of their output. So they were all assessed with "n/a". The remainder of this analysis hence focuses on the 12 explicit risk tools in the sample.

With regards to firm valuation metrics, 6 out of the 12 risk tools provide a climate-adjusted firm value (based on various firm valuation approaches). Climate-adjusted cost of capital and the climate-adjusted value of assets in the liquidation case are not provided as standard tool output, but can be calculated or provided on a customized basis in two and one case, respectively. Financial asset risk and valuation metrics are provided by 11 of the 12 risk tools. Climate-adjusted expected returns and value at risk are most widely provided, with 8 out of the 12 tools, each. From these 8 tools, 5 cover both metrics. This shows that expected returns and value at risk can be assessed together, in order to cover a financial valuation and a financial risk metric. Climate-adjusted asset prices and maximum drawdown are provided by five and four tools, respectively. Most of these tools also provide the climate-adjusted expected returns and value at risk. A climate-adjusted alpha, beta, CAPM factor, standard deviation, $R^2$, Sharpe or Sortino ratio are never part of the standard tool output, and can only be calculated with the provided output in a second step, or in a customized setting by two of the financial services tool providers. Benchmarks for these metrics can be adjusted by tool providers for taking into account climate risks, as long as they are able to analyse equity portfolios.[26] The most widely provided credit risk metrics are a climate-adjusted probability of default (9 out of 16 tools) and a climate-adjusted credit rating (7 out of 16 tools). Climate-adjusted loss given default and distance to default are provided by six tools. Since probability of default directly enters the loss given default and the distance to default, these six tools cover also the probability of default. Furthermore, all seven credit rating tools also provide the probability of default. Three financial services tool providers, two academic institutions and one think tank provide a broad variety in climate-adjusted financial metrics. Three tools focus exclusively on specific climate-adjusted financial metrics: One focuses on value at risk, one on expected returns, and one on probability of default and credit risk.

[25] For example, the lower the extent of investments in renewable energies, the more CCS investments would be required; the more emission overshoot, the more carbon sinks -natural or technological would be required, with associated trade-offs on land use for food and bioenergy

[26] It remains to be seen to which extent the recently amended EU benchmark regulation with the two new benchmark categories, the Climate Transition Benchmarks (CTBs) and the Paris-aligned Benchmarks (PABs), will have and impact on using climate risk-adjusted benchmarks in the future.

In sum, tools mainly focus on climate-adjusted financial asset metrics (value at risk and expected returns) and credit risk metrics (probability of default and credit rating). Climate-adjusted firm valuation metrics are less provided. However, firm valuation metrics are the basis for fundamentals-driven financial asset valuation. As long as markets do not seem to not fully capture climate-related transition risks, market-based valuation approaches are likely to be misleading. In this context, developing the tools further to improve climate-adjusted firm valuations and provide climate-adjusted cost of capital should be a key priority.[27] Furthermore, financial asset risk and valuation metrics like alpha, beta and the Sharpe ratio play an important role for investment decisions. As long as these metrics are not climate-adjusted, they might be misleading. Since they are market-based, and usually based on backward-looking data, they might need to be complemented by forward-looking fundamentals-based approaches.[28]

[27]This might also hold for physical risk, but it goes beyond the scope of the present study.

[28]Financial models to derive these metrics in theory and practice often rely on a pre-defined probability distribution. This is usually a normal probability distribution, or a probability distribution as derived from past data. Yet, climate risks are unprecedented i.e. it lacks data to identify the probability distribution. Climate risks are mostly associated with non-normal distributions and fat tails.(Thomä and Chenet, 2017; Roncoroni et al., 2019). Therefore, it is important to find an appropriate way to adapt the metric's underlying probability distributions to reflect the climate-related risk structure.

**Tool coverage: Risk sources and realisations**

| Risk source & realisation | 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Policy** | | | | | | | | | | | | | | | | |
| Smooth | x | - | x | x | (x) | x | x | x | x | x | x | n/a | x | x | (x) | x |
| Shock | x | x | x | - | x | x | - | x | x | (c) | (c) | n/a | x | x | (x) | x |
| **Market upstream (supply chain)** | | | | | | | | | | | | | | | | |
| Smooth | (c) | - | x | x | x | x | - | x | x | x | (c) | n/a | (c) | - | (x) | x |
| Shock | (c) | x | x | - | x | x | - | x | x | (c) | (c) | n/a | (c) | - | (x) | x |
| **Market downstream (demand)** | | | | | | | | | | | | | | | | |
| Smooth | (c) | - | x | x | x | x | - | x | x | x | (c) | n/a | (c) | - | (x) | x |
| Shock | (c) | x | x | - | x | x | - | x | x | (c) | (c) | n/a | (c) | - | (x) | x |
| **Technology** | | | | | | | | | | | | | | | | |
| Smooth | (c) | - | x | x | - | x | x | x | x | x | (c) | n/a | - | x | (x) | x |
| Shock | (c) | x | x | - | - | x | - | x | x | (c) | (c) | n/a | - | (c) | (x) | x |
| **Other** | | | | | | | | | | | | | | | | |
| | | | | | | | | | financial disruption | | | | | | divestment | |

x: covered — (x): indirectly covered (e.g. via market expectations) — (c): only in customized approach — -: not covered — n/a: not applicable — .: information not available or confidential — dvp: under development

Sources: Study questionnaire, tool documentation

Table 8: Tool coverage: Risk sources and realisations

## Tool coverage: Financial assets

| **Financial asset** | **Tool** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
| **Individual assets** | | | | | | | | | | | | | | | | |
| Stocks | x | x | - | - | x | x | x | - | x | x | x | n/a | - | x | x | x |
| Bonds - corporate | x | x | - | - | x | x | . | x | x | x | x | n/a | x | x | x | x |
| Bonds - government | x | x | - | - | x | x | . | - | x | - | x | n/a | - | - | x | x |
| Loans - corporate | x | x | - | - | x | x | . | x | x | x | x | n/a | x | x | x | x |
| Loans - project | x | - | - | - | x | x | . | - | - | x | (c) | n/a | - | - | x | x |
| Mortgages | - | - | - | - | x | x | . | - | x | x | - | n/a | - | - | - | x |
| Credits (personal loans) | (c) | - | - | - | x | x | x | - | - | x | x | n/a | - | - | (c) | - |
| Real assets | x | - | - | x | x | x | - | - | x | dvp | dvp | n/a | - | - | - | x |
| Options & Derivatives | - | x | - | - | - | (c) | - | - | x | dvp | - | n/a | - | - | (c) | - |
| **Aggregated assets** | | | | | | | | | | | | | | | | |
| Portfolios | x | - | - | x | x | x | x | x | x | x | x | n/a | - | - | x | x |
| Funds | x | - | - | - | x | x | x | - | x | x | x | n/a | - | - | x | x |
| **Other** | | | | | | | | | | | | | | | | |
| | | | financial flows | | | | | | | | | dvp: FI targets | | | | |

x: covered — (c): only in customized approach — -: not covered — n/a: not applicable — .: information not available or confidential — dvp: under development

Sources: Study questionnaire, tool documentation

Table 9: Tool coverage: Financial asset types

**Tool input: Climate scenarios**

| **Scenario** | **Tool** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
| **IEA** | | | | | | | | | | | | | | | | |
| IEA ETP scenarios* | x | (c) | (c) | x | x | x | - | - | - | x | x | - | (c) | - | - | (c) |
| IEA WEO/WEM scenarios** | x | (c) | (c) | x | - | x | - | - | - | x | x | - | (c) | - | - | (c) |
| **IAMs** | | | | | | | | | | | | | | | | |
| REMIND (PIK) - MAgPIE (IIASA) scenarios*** | - | - | (c) | - | - | - | x | x | - | dvp | - | - | x | - | - | (c) |
| MESSAGEix-GLOBIOM scenarios | - | - | (c) | - | - | - | - | x | - | - | x | - | (c) | - | - | (c) |
| **Other** | | | | | | | | | | | | | | | | |
| Greenpeace Energy [R]evolution | x | (c) | (c) | - | - | - | - | - | - | (c) | - | - | (c) | - | - | (c) |
| PRI IPR: Forecast Policy Scenario | - | (c) | (c) | - | - | - | - | - | - | - | - | - | - | - | - | x |
| Own scenario | - | - | x | - | - | - | - | x | x | - | - | x | (c) | - | - | x |

x: covered — (c): customized / scenarios adaptable — -: not covered — n/a: not applicable — .: information not available or confidential — dvp: under development
* e.g. RTS and B2DS/2DS/4DS/6DS — ** e.g. CPS and STEPS/SDS — *** e.g. NGFS reference scenarios

Sources: Study questionnaire, tool documentation

Table 10: Tool setup: Climate Scenarios

### Tool output: Climate-adjusted financial metrics

| Financial risk/valuation metric | Tool | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
| **Firm valuation** | | | | | | | | | | | | | | | | |
| Firm value (market cap/EV) | n/a | x | - | (x) | n/a | (c) | x | - | - | - | n/a | n/a | - | x | - | x |
| Cost of capital | n/a | - | - | (x) | n/a | (c) | - | - | - | - | n/a | n/a | - | - | - | - |
| Assets value in liquidation case | n/a | - | - | - | n/a | (c) | - | - | - | (x) | n/a | n/a | - | - | - | - |
| **Financial asset risk / valuation metric** | | | | | | | | | | | | | | | | |
| Asset price | n/a | x | - | - | n/a | (c) | - | x | x | (x) | n/a | n/a | - | - | - | x |
| Expected returns | n/a | x | - | - | n/a | (c) | - | x | x | x | n/a | n/a | - | (x) | x | (x) |
| Expected dividends | n/a | x | - | - | n/a | (c) | - | x | - | (x) | n/a | n/a | - | - | - | x |
| Alpha **) | n/a | - | - | - | n/a | (c) | - | - | - | (x) | n/a | n/a | - | - | x | - |
| Beta **) | n/a | - | - | - | n/a | (c) | - | - | - | (x) | n/a | n/a | - | - | x | - |
| CAPM factor | n/a | - | - | - | n/a | (c) | - | - | - | (x) | n/a | n/a | - | - | x | - |
| Standard deviation | n/a | - | - | - | n/a | (c) | - | - | x | (x) | n/a | n/a | - | - | x | - |
| R-squared **) | n/a | - | - | - | n/a | (c) | - | - | - | - | n/a | n/a | - | - | x | - |
| Sharpe ratio **) | n/a | - | - | - | n/a | (c) | - | - | x | (x) | n/a | n/a | - | - | x | - |
| Sortino ratio **) | n/a | - | - | - | n/a | (c) | - | - | x | (x) | n/a | n/a | - | - | - | - |
| Value at risk | n/a | x | x | (x) | n/a | (c) | x | - | x | (x) | n/a | n/a | - | - | x | x |
| Maximum drawdown | n/a | x | - | - | n/a | (c) | - | - | x | - | n/a | n/a | - | - | x | - |
| **) adjusted benchmark | | | | | | (c) | | | (c) | (c) | | | | | dvp | |
| **Credit risk metrics** | | | | | | | | | | | | | | | | |
| Probability of default | n/a | x | - | - | n/a | (c) | x | x | x | (x) | n/a | n/a | x | x | x | x |
| Loss given default | n/a | x | - | - | n/a | (c) | x | x | x | - | n/a | n/a | - | - | - | x |
| Value of collateral | n/a | - | - | - | n/a | (c) | - | x | (x) | (x) | n/a | n/a | - | - | - | (c) |
| Distance to default (Merton) | n/a | x | - | - | n/a | (c) | x | x | - | - | n/a | n/a | - | x | - | x |
| Credit rating | n/a | - | - | - | n/a | (c) | x | x | x | (x) | n/a | n/a | x | x | - | x |
| **Other** | | | | | | | | | | | | | | | | |
| | | | central bank interest rates | | | (c) | | | various | | | | | | | |

x: available as tool output — (x): can be easily calculated with tool output — (c): only in customized approach — -: not available — n/a: not applicable — .: information not available or confidential — dvp: under development

Sources: Study questionnaire, tool documentation

Table 11: Tool output: Financial risk / valuation metrics

## 5.2 Criteria-based analysis

As explained in Section 4, the criteria-based analysis covers the three dimensions accountability, depth of risk analysis, and usability. In this section, we report and describe the results of the criteria-based tool analysis. The overview results are displayed in Figure 10. In order to provide potential tool users information to identify useful tools for their individual use cases, we also report the full analysis for each tool in Table 12.

In sum, as shown in Figure 6, 13 of the 16 tools in our sample fulfil all criteria to medium extent. Only 3 tools display high overall criteria fulfilment. On the individual dimensions, accountability is medium for 12 tools, and only 4 tools perform high on this important dimension. The depth of risk analysis is high for 7 tools, and medium for 9 tools. On the usability, we find low performance for 2 tools, medium performance for 12 tools, and high usability for only 2 tools. We find that accountability is on average high for the tools from academia and think tanks, and medium for financial service providers. This result is mainly driven by the low transparency of all financial service providers. The depth of risk analysis is on average high for tools from financial service providers. Academia and think tanks have on average medium depth of risk analysis with very diverging values for the individual tools. Finally, usability is on average medium for all three tool provider types.

This general overview shows that it is in general feasible to perform high on all criteria altogether, and on the three individual core dimensions. Yet, it also indicates that, based on our criteria, there is still considerable scope to improve the tools to derive high quality, comparable and decision-relevant climate-adjusted financial risk metrics. The results are discussed in detail in the following sections.

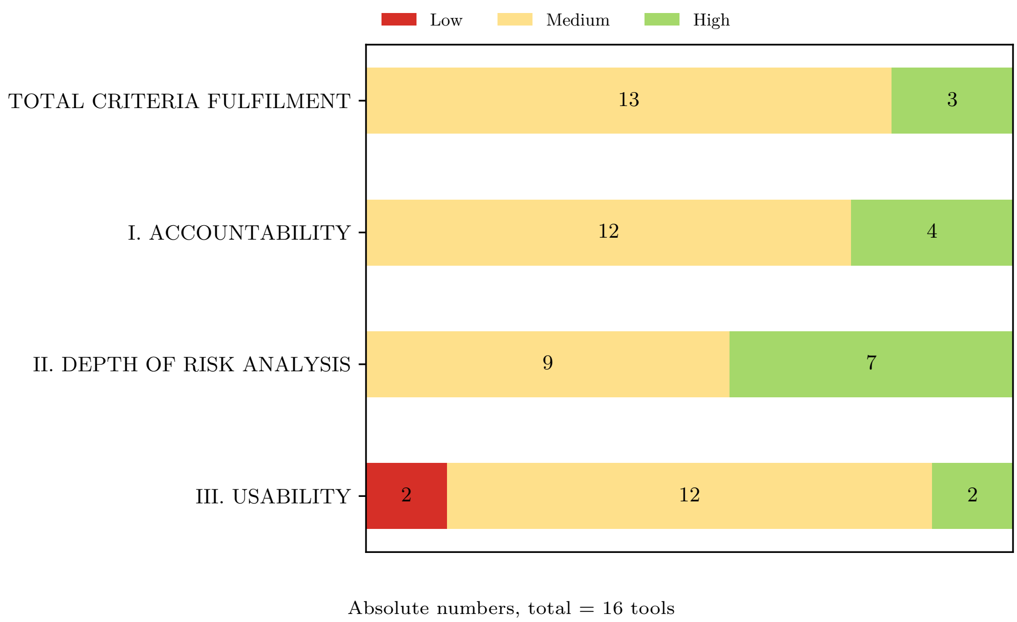


Figure 6: Criteria analysis results summary

### 5.2.1 Accountability

Overall, only 4 out of the 16 analysed tools perform high with regards to the accountability dimension, meaning that they produce output, which is verifiable by users and external experts in the field, based on a careful data strategy. For the majority of 12 tools, accountability could be improved.

Public transparency is a key criterion for accountability. The analysis sample consists of tools, whose providers complete the extensive study questionnaire. The vast majority of tool providers (13 of 16 tools) was willing to provide all required information for this study, and publish the results of the tool analysis in the Tables and the Appendix. This is an important step towards public transparency, and tool accountability. However, this element does not count in the meta assessment of tools, since it is something that can only be fulfilled in the context of this study. When considering the public transparency of the model code and the model setup, we find that 10 out of 16 tool providers do not fulfil this criterion, as can be seen in Figure 7. Additional four tools do not yet provide enough information to perform well on transparency, which would be key to better understand their output, enable the correct interpretation of results and launch into science-based exchange and improvement of the tools.

The majority of tools (9 out of 16) perform relatively well on the emission data strategy. This result is mainly driven by the fact that data sources are well reported by the vast majority of tools (14 out of 16), and a majority of 10 tool providers explicitly explains the missing data strategy. Yet, only 3 tools use third party verified data. This being said, 11 tools rely on own strategies to verify the emission data. Third party verification is an important determinant of better data quality, and avoids conflicts of interest in commercial relations between tool providers, users and investees.

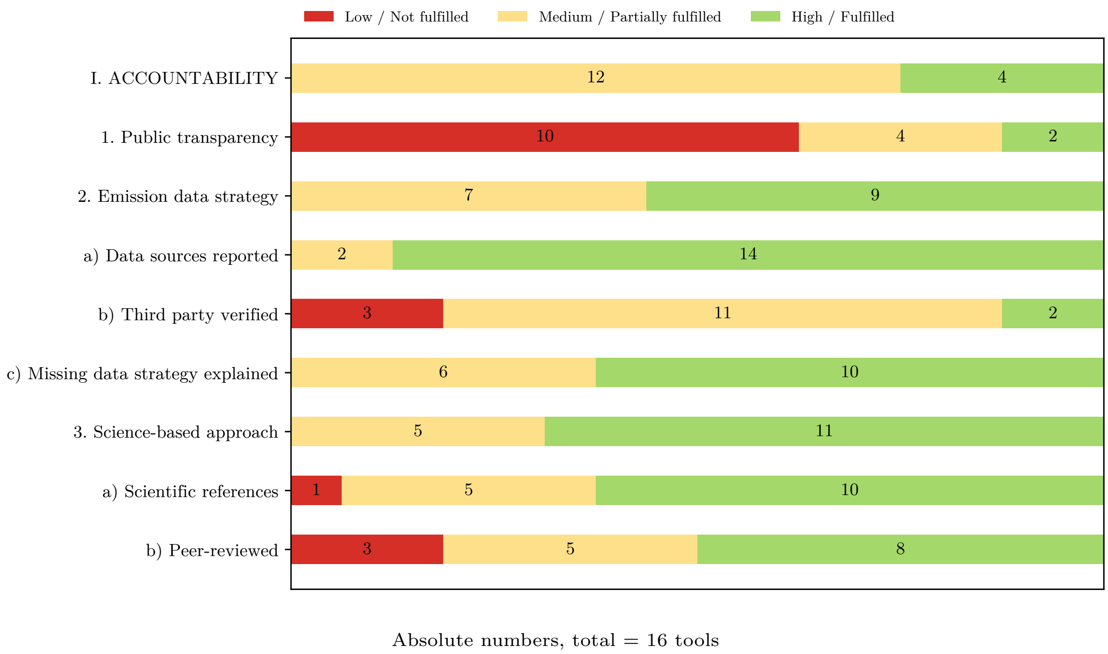


Figure 7: Accountability results

Whilst many tools claim to perform a science-based approach, we find that 11 of the 16 tools fulfil this criterion in our analysis. We see that 10 tools build on academic publications and use scientifically developed scenarios. Yet, we also see that 6 tools perform medium or even low on scientific references. Half of the tools are not peer-reviewed. Yet, of these, 5 tools are still somehow scientifically documented in working papers, and are hence in principle available for peer reviews by the academic community. For 3 tools, scientific review is not possible, because their approach is not available at all. This means that there is still room for improvement of the scientific basis of many tool approaches, and tool providers should aim for peer-reviews to ensure quality and the scientific state of the art of their approach.

Overall, it is important to note that the combination between the transparency criterion and the peer-review are most important cornerstones of accountability. With only 8 of the 16 tool approaches being peer-reviewed, and only two tools that provide full access to their model setup and code (one from academia, one think tank), regulators should consider to ask for better scientific documentation of the approaches. This would also foster the exchange between tool providers, climate scientists, social scientists, economists and finance researchers, which is required to further improve the approaches.

### 5.2.2 Depth of risk analysis

An appropriate risk assessment hinges on the depth of risk analysis. In this context, it is important to note that risk is often used as a synonym for hazard and exposure. However, these are only two aspects of risk.[29] Vulnerability and resilience, adaptability, and economic impact are additional aspects for meaningful risk analyses. Furthermore, tools ideally also cover risk amplification mechanisms. In the following, we describe some of the most important results for the depth of risk analysis. The full results can be seen in Figure 8. Overall, tool providers face a significant trade-off between depth of risk analysis and modelling complexity. The further we go along the risk aspects chain, the less tools cover the respective aspect fully, partially, or on a customized basis. Furthermore, we see that some tools have a relatively low depth of risk analysis. This is due to the fact that their tools were not designed as risk tools, but as alignment, impact, or target setting tools. The output of these tools reflects hazard and exposure, but not vulnerability, adaptability, economic impact and amplification mechanisms.

As can be seen in Figure 8, hazard coverage is high for 12 of the 16 tools. 11 tools provide a 1.5/<2°C scenario. 3 tools do not provide analyses based on a 1.5/<2°C scenario, and 2 tools only on a customized basis. Yet, the Paris Agreement asks all states to limit global temperature increase to 1.5/<2°C. This means that results from tools which do not provide a 1.5/<2°C scenario might not capture the relevant potential hazard. For the customized offers, clients would need to be aware of the global climate targets and of the different implications between 1.5/<2°C scenarios and 2°C scenarios to ask for meaningful risk analyses, which might not always be the case. Most tools differentiate between countries (10 out of 16), and sectors (15 out of 16) when modelling hazard. This is important, since climate transition risks could significantly differ by country and sector.

Current GHG emissions are used by all tools of the present study to model exposure, although for some tools, GHG emissions are only a minor risk factor. 8 of the 16 tools take all three emission

[29] For example, sectoral climate risk heat maps are basically hazard-exposure tools. They can be used for a first screening to decide where further climate risk analysis would be required, but they do not provide a company-specific risk analysis.

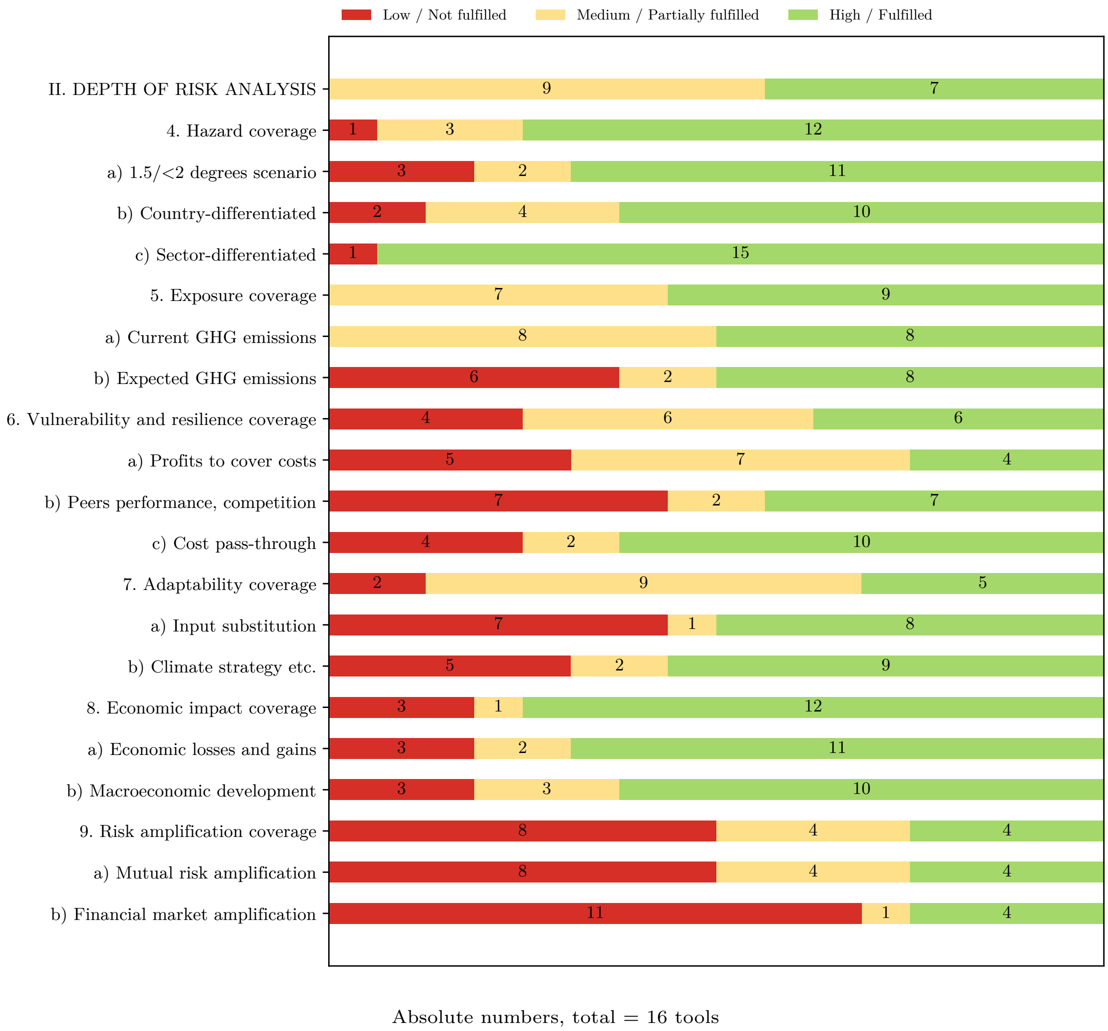


Figure 8: Depth of risk analysis results

scopes into account and GHG emissions other than $CO_2$, and/or perform a proper materiality assessment to make sure that most important GHG and scopes are featured in the analysis. The second half of the sample could improve on this point. More important, we see that with 8 of 8 tools, most analyses do not sufficiently make use of forward-looking data, i.e. expected emissions. Yet, these forward-looking emission data are an important complement to the forward-looking (usually scenario-based) hazard modelling.

Vulnerability and resilience coverage could be improved. Only 6 of the 16 tools cover it in the standard setting, another 6 tools model vulnerability and resilience only partially or on a customized basis. Cost pass-through is most often used to model vulnerability and resilience (10 of 16 tools provide it in the standard setting), whilst peers performance and competition aspects are not considered at all by 7 tools. The latter is a significant shortcoming with regards to financial decision-relevance. Profits as a buffer to cover additional transition-induced costs or lower revenues are covered by 4 tools, only.

With regards to adaptability, only 5 of the 16 tools include this aspect in the standard analysis. However, 9 tools cover it to some extent or on a customized basis. Input substitution and climate strategies, R&D expenditures and future CAPEX-plans are considered by 8 and 9 tools, respectively. However, it needs to be considered that of the 9 tools, which cover climate strategies, 4 tools are not risk tools but alignment, target setting or input tools. Furthermore, climate strategies might not be credible, or not sufficient in scale and speed to be aligned with the climate targets. Using future-related current expenditures like investments in R&D could be more reliable indicators for future adaptability.

The economic impact is covered by the large majority of tools. Only 3 tools do not capture this aspect, all of which are not risk tools but alignment, target setting or impact tools. Besides losses and gains, the macroeconomic developments are relatively well covered, too.

Risk amplification mechanisms are not sufficiently covered, yet. The mutual amplification of various risk sources is not covered by 8 of the 16 tools, and financial market amplification mechanisms are even less covered: 11 out of 16 tools completely miss out on this aspect. A reason might be the challenge to model endogenous developments in climate policy transition scenarios, translate these into economic models, and then use the economic model outputs to feed into the climate scenarios, and beyond. However, ongoing progress in the climate policy transition scenario modelling community suggests that such analyses might become available in the near future.

Overall, we find that the depth of risk analysis varies considerably amongst tools. In general, there are some approaches available (at least on a customized basis) where the risk analysis captures all important aspects. However, this finding needs to be interpreted with caution, since tool providers had an incentive to tick many boxes in the questionnaire, to make themselves attractive for potential users. Furthermore, as has been highlighted by some advisory board members, the quality of the coverage of the individual risk aspects might differ significantly. For example, one advisory board member stressed that cost pass-through and input substitution are often not done well enough for confident usability in most investment processes. Such quality assessments go beyond the scope of the present study, but potential users should be aware of this limitation.

#### 5.2.3 Usability

Usability in the sense of theoretical robustness captures the degree to which outputs are interpretable, and to which degree the tools are able to capture uncertainties.[30] As can be seen in Figure 9, only two tools perform high on usability. The vast majority (12 of the 16 tools) performs medium, and two tools have low usability for financial climate transition risk analyses.

With regards to output interpretability, we find that 11 out of the 16 tools performs only medium. This could be a significant issue when using the output for decision-making. However, this criterion could be relatively easily improved by tool providers. Whilst all tools report their model structure, scenarios, and assumptions at least to their clients. However, of these, only a minority of six tools publicly discloses this relevant information (as could be seen in Figure 7 in the results for the transparency-criterion). This means that users of reported risk data like financial supervisory authorities might struggle to correctly interpret the risk as reported by the financial institution. Furthermore, the correct interpretation of the tool output could be challenging, even if assumptions and key drivers are generally disclosed. Therefore, it could be useful that tool output is communicated in direct relation to the assumptions, for example by aid of a standardised sentence. However, we find that none of the tools communicates the output in such a manner.

[30] Usability in the sense of actual investment relevance is captured in the descriptive analysis sections on asset coverage, section 5.1.2, and tool output, section 3.

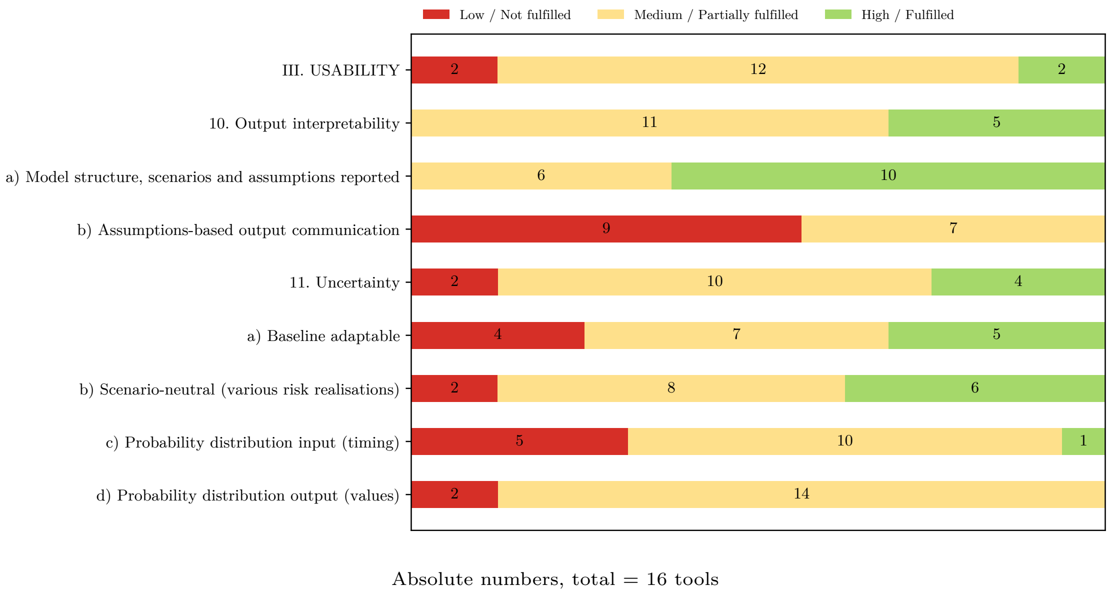


Figure 9: Usability results

7 tools communicate key assumptions and modelling choices in the output report, which is an important first step. However, 9 out of the 16 tools do not fulfil this criterion at all, which is a serious shortcoming in the aim to improve the understanding of climate-related financial risks in practice. Improving performance on this element should not be too much of an effort for tool providers, hence regulatory authorities might want to consider to define common reporting guidelines for tool providers and/or tool users, when they report climate risks in financial disclosures or for microprudential analysis.

With regards to uncertainty, we find that only 4 tools have a high coverage of uncertainty. 2 tools are in general not able to capture uncertainty, which is a significant shortcoming, and 10 tools perform medium with regards to this criterion. Taking low and medium flexibility together, 14 out of 16 tools allow users to analyse various possible transition developments. Of these, 8 tool providers allow users to assess various transition trajectories, which are to be chosen from a pre-defined set of scenarios. Only 6 tools are fully scenario-neutral. Scenario-neutral tools have one major advantage over tools with a pre-defined set of scenario choices: They could more flexibly deal with the current dynamics in scenario modelling, and use more up to date scenarios (e.g more granular scenarios, or scenarios which cover the trade-off between physical risks and transition risks). Only 2 tools are not flexible at all, which also directly translates into their general ability to deal with uncertainty. The baseline is not adaptable for 4 tools. The majority of tools allows to select between different pre-defined baseline specifications or to adapt the baseline flexibly. Only 1 tool explicitly considers a probability distribution of possible input realisations (i.e. the risk timing). Yet, the majority of tools allows users to flexibly adapt the timing of the risk realisation. None of the tools provides its output values by default as a probability distribution, determined by the probability distribution of risk realisations, and various modelling choices. As a remedy to this currently underdeveloped feature, users could ask tool providers to run the model multiple times with different assumptions and scenarios to generate a probability distribution of possible outcomes and output values in a customized approach. This would in general be feasible for the

14 tools, which allow users to somehow adapt the transition pathway, as captured by the "scenario neutral" criterion.

Overall, usability of tools still needs to be improved. Whilst this is a relatively easy task for output interpretability, tools should also develop further to base their input and output on probability distributions. In addition, it would be important that regulators develop a standard way to communicate key assumptions and modelling choices in the same sentence as the tool output, to foster correct interpretation and understanding of the entire modelling exercise.

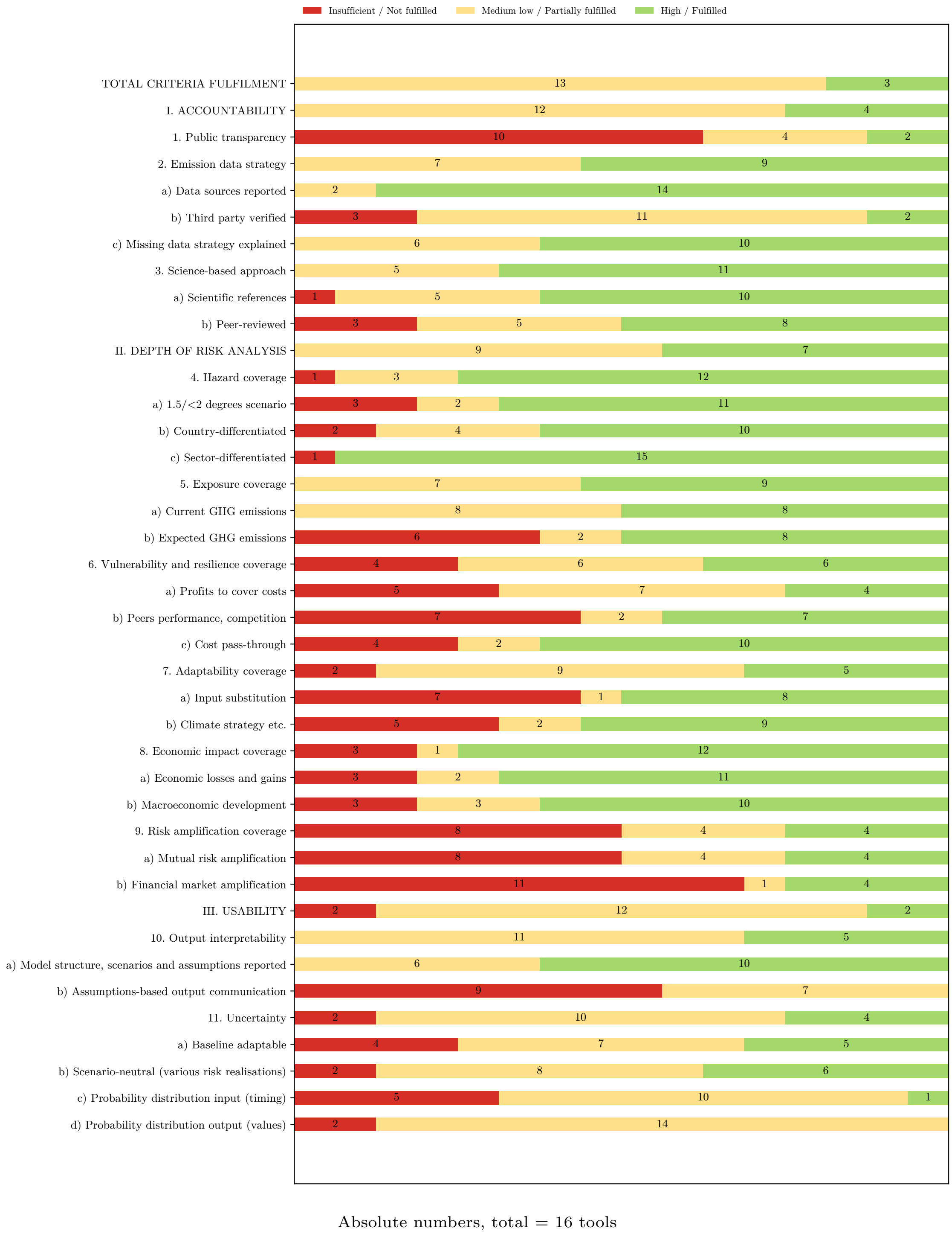


Figure 10: Overview all criteria results

| | Tool | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Criterion | 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
| **I. ACCOUNTABILITY** | | | | | | | | | | | | | | | | |
| **1. Public transparency** | | | | | | | | | | | | | | | | |
| a) Model modules, code public | x | (x) | (x) | - | - | - | - | - | - | - | (x) | (x) | - | - | x | - |
| b) Study questionnaire completed* | x | (x) | x | x | (x) | x | (x) | x | x | x | x | x | x | x | x | x |
| **2. Emission data strategy** | | | | | | | | | | | | | | | | |
| a) Data sources reported | x | x | x | (x) | x | x | x | x | (x) | x | x | x | x | x | x | x |
| b) Third party verified | (x) | (x) | - | (x) | (x) | (x) | (x) | (x) | (x) | (x) | x | - | - | (x) | x | (x) |
| c) Missing data strategy explained | x | (x) | (x) | (x) | x | x | x | x | (x) | (x) | (x) | x | x | x | x | x |
| **3. Science-based approach** | | | | | | | | | | | | | | | | |
| a) Scientific references | x | x | x | x | (x) | (x) | x | (x) | x | x | x | (x) | (x) | - | x | x |
| b) Peer-reviewed | x | x | x | (x) | - | (x) | (x) | - | (x) | x | x | x | - | x | x | (x) |
| **II. DEPTH OF RISK ANALYSIS** | | | | | | | | | | | | | | | | |
| **4. Hazard (shock / smooth transition)** | | | | | | | | | | | | | | | | |
| a) 1.5/<2°C scenario | x | x | x | - | - | x | x | x | x | x | x | x | (c) | (c) | - | x |
| b) Country-differentiated | (c) | x | x | x | (x) | (c) | x | x | x | (x) | x | - | x | x | - | x |
| c) Sector-differentiated | x | x | x | x | x | x | x | x | x | x | x | x | x | x | - | x |
| **5. Exposure** | | | | | | | | | | | | | | | | |
| a) Current GHG emissions | (x) | x | x | (x) | x | x | (x) | x | (x) | (x) | x | x | (x) | x | (x) | (x) |
| b) Expected GHG emissions | x | - | x | - | n/a | (c) | - | x | - | x | x | n/a | x | x | (x) | x |
| **6. Vulnerability & Resilience** | | | | | | | | | | | | | | | | |
| a) Profits to cover costs | n/a | (x) | (x) | - | n/a | (c) | (x) | x | - | x | (x) | n/a | x | (x) | (x) | x |
| b) Peers performance, competition | n/a | x | - | - | n/a | x | (x) | x | - | x | - | n/a | x | x | (x) | x |
| c) Cost pass-through | n/a | x | x | - | n/a | (c) | x | x | x | x | x | n/a | x | x | (x) | x |
| **7. Adaptability** | | | | | | | | | | | | | | | | |
| a) Input substitution | n/a | x | x | - | n/a | x | - | x | x | x | x | n/a | - | - | (x) | x |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | - | - | - | x | x | x | x | - | x | x | = tool output | - | x | (x) | (x) |
| **8. Economic impact** | | | | | | | | | | | | | | | | |
| a) Economic losses and gains | n/a | x | x | x | n/a | (x) | x | x | x | x | x | n/a | x | x | (x) | x |
| b) Macroeconomic development | n/a | x | x | (x) | n/a | x | x | x | x | x | x | n/a | x | (x) | (x) | x |
| **9. Risk amplification** | | | | | | | | | | | | | | | | |
| a) Mutual risk amplification | n/a | (c) | x | - | n/a | (c) | - | x | x | - | x | n/a | (x) | - | (x) | - |
| b) Financial market amplification | n/a | x | dvp | - | n/a | (c) | - | x | x | - | - | n/a | - | - | x | - |
| **III. USABILITY** | | | | | | | | | | | | | | | | |
| **10. Output interpretability** | | | | | | | | | | | | | | | | |
| a) Model structure, scenarios and assumptions reported | x | x | x | x | (x) | (x) | (x) | (x) | x | x | x | x | (x) | x | x | x |
| b) Assumptions-based output communication | (x) | - | (x) | - | - | - | . | - | - | (x) | (x) | - | (x) | (x) | - | x |
| **11. Uncertainty** | | | | | | | | | | | | | | | | |
| a) Baseline adaptable | x | x | x | (x) | - | (x) | x | (x) | (x) | (x) | - | - | (c) | (c) | - | x |
| b) Scenario-neutral (various risk realisations) | x | x | x | (x) | - | (x) | x | (x) | (x) | (x) | x | (x) | (x) | (x) | - | x |
| c) Probability distribution input (timing) | dvp | x | (x) | (x) | n/a | (c) | (c) | (c) | (c) | - | (x) | n/a | (x) | (x) | - | (x) |
| d) Probability distribution output (values) | (c) | (c) | (c) | (c) | n/a | (c) | (c) | (x) | (x) | (c) | (c), dvp | (x) | (c) | (c) | - | (c) |

x: fulfilled — (x): partially fulfilled — (c): only in customized approach — -: not fulfilled — n/a: not applicable — .: information not available or confidential — dvp: under development

Sources: Study questionnaire, tool documentation

*) Documented in the results, but does not count into the meta analysis

Table 12: Tool assessment: Criteria-based analysis

## 5.3 Further use analysis

This study also collected information on whether the analysed tools cover physical risks or could be useful to support the progress towards achieving the international climate targets. [31]

With regards to physical risks, 10 of the 16 tools cover these either by default or in a customized setting, and two further tools are currently developing their physical risk approach. The trade-off between physical and transition risks is much less included in the analyses: Only two financial service provider tools explicitly capture this element, one academic institution covers the trade-off on a customized basis. If more scenarios become available, which reflect the trade-off between physical impacts and transition developments, the scenario-neutral tools should in principle be capable to capture this element.

As mentioned above, it is currently highly debated whether financial institutions could at all claim that they reduce real emissions with their investment decisions to contribute to the climate targets. Nevertheless, this study also asked whether tool providers could in principle assess the alignment of investment decisions with the climate targets.[32] With 11 of 16 tool providers, the majority provides alignment assessments either in the standard setting, partially or on a customized basis. And three tool providers are currently developing alignment assessment methods to make them part of the standard assessment package. With regards to the highly debated question, the real impact of financial institutions' investment decisions on global GHG emissions, only one tool provider states that they could provide a complete assessment of a Financial Institutions' climate impact. Another tool covers this question partially, and a third tool in a customized setting.

Overall, transition tools seem to expand their analysis into physical risk and alignment areas. Tools that are able to assess the trade-off between physical and transition risks would be quite useful, but scenarios still need to be developed further in this area. Last, it remains to be seen how the ongoing debate about financial institutions' direct climate impact will be informed by further research, and how tools will develop in this regard.

[31] See, for instance, the physical risk assessment done for all major UK banks by Westcott et al. (2020)

[32] Selling and buying financial assets could align a portfolio with the climate targets, but re-allocations do not necessarily contribute to real GHG emission reductions. Further research would be required to provide a more concise assessment of this issue.

| Criterion | Tool 2DII | CFIN | CAME | CISL | CAR4 | ISSE | MSCI | OLWY | ORTE | PWC | RIGHT | SBTI | SPCM | SPPD | UNIA | VIVE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FURTHER USE** | | | | | | | | | | | | | | | | |
| **Physical risks** | | | | | | | | | | | | | | | | |
| a) Physical risks covered | (c) | (c) | x | (x) | (x) | x | x | dvp | x | dvp | - | - | - | dvp | - | x |
| b) Trade-off physical-transition risks | - | (c) | dvp | dvp | - | dvp | - | - | x | - | - | - | - | - | - | x |
| **Climate targets** | | | | | | | | | | | | | | | | |
| a) Alignment assessment | x | x | (x) | (x) | x | x | x | - | dvp | (c), dvp | x | (x), dvp | - | - | - | x |
| b) FI impact analysis | - | - | - | - | (x) | (c) | - | - | - | - | x | - | - | - | - | - |

x: fulfilled — (x): partially fulfilled — (c): only in customized approach — -: not fulfilled — n/a: not applicable — .: information not available or confidential — dvp: under development

Sources: Study questionnaire, tool documentation

Table 13: Tool assessment: Further use analysis

# 6 Conclusion

This study had two aims. First, we identified criteria to assess climate risk tools for financial decision-making. These criteria could serve as a first step towards developing a comprehensive theory of climate transition risk indicators for financial decision-making, which is currently lacking. Furthermore, we assessed the state of the art of currently available climate risk tools by aid of a sample of 16 tools, using descriptive and criteria-based analysis. The results of the meta analysis highlighted strengths, key gaps and areas to improve financial climate risk tools.

With regards to tool coverage, we found that most important risk sources and realisations are relatively well covered across the tool sample. However, few tools cover all analysed risk sources and the interaction among them - despite the fact that the risk sources could mutually reinforce each other. It would hence be beneficial for further tool developments to cover policy, market upstream, market downstream and technology transition risk sources, and to capture that risk sources could reinforce each other.

The coverage of financial assets is best for publicly traded asset classes in the analysed sample thanks to data availability. Moreover, each asset class is covered by more than two tools. Mortgages and real assets are one of the main target of low-carbon policy intervention, but not sufficiently covered, yet. The same holds for project loans, which could be of increasing relevance in the low-carbon transition phase. The study highlighted that developing tools further in this direction will be desirable in order to more comprehensively risk exposure of different asset classes, yet data challenges need to be overcome.

The vast majority of tool providers relies on some climate scenarios, but an increased transparency about the assumptions of each scenario might be desirable. We found that most tools use scenarios from the IEA, or IAMs. This is because these scenarios present desirable characteristics for the analysis of transition risk. However, both types of scenarios also exhibit significant shortcomings. This study therefore argues that scenario neutrality would be a desirable feature of any climate risk tool.

When it comes to the tool outputs, most of the tools in the analysis sample mainly focus on climate-adjusted financial asset metrics (value at risk and expected returns) and credit risk metrics (probability of default and credit rating). However, it has been argued that, given the likely undervaluation of climate-related risks in financial markets, firm valuation metrics for improved fundamental analysis approaches should be further developed. Furthermore, important financial metrics like alpha, beta and the Sharpe ratio are not readily available on a climate-adjusted basis, yet. The study acknowledged the challenges related to a climate-adjusted alpha, beta or Sharpe ratio - yet we also argued that further tool developments should try to find a way to cover these important financial metrics, too.

In the criteria-based assessment, we analysed the three dimensions accountability, depth of risk analysis, and usability, by aid of 10 assessment criteria. It has been argued that the main issue for accountability is currently the combination of low transparency of the tools' specific setup, with the lack of peer-reviewed publications of the tool approaches. This also hinders a broader scientific exchange between tool providers, climate scientists, social scientists, economists and finance research, which would be required to further improve the analysis approaches.

The study also finds that the depth of risk analysis varies considerably amongst tools. Depending on the use case, tool users need to be aware that the output might capture only specific risk aspects. To date, most tools are not able to assess mutual risk amplifications and financial amplification mechanisms. Yet, this would be two very important aspects for risk assessments of individual financial institutions, given their relatively high exposure to other financial actors, and for micro- and macroprudential financial supervision.

Furthermore, the criteria-based analysis shows that the usability of tools needs improvement. Most tool providers do not make their model codes and model description publicly available; however they allow their clients and tool users to access the model setup and underlying assumptions. This is important for the correct interpretation of tool outputs. Yet, the limited transparency prevents peer reviews of their setup. Hence, it would be of high importance that public transparency, based on standardised frameworks to ease the understanding of assumptions and key characteristics of scenarios and further modelling, would become a basic requirement for climate risk tool providers. This would help to ensure quality and comparability of tool outputs. Furthermore, we find that tools could improve to build their output on probability distributions of possible input realisations and possible tool outcomes to account for uncertainty. They further could significantly improve on how and which information about key assumptions when communicating the final output is provided in direct relation to the output figures. Furthermore, we find that scenario-neutrality (or at least a certain extent of scenario flexibility) would be a desirable feature, such that tool users do not have to rely on specific scenarios, use various specifications, and reflect the state of the art of climate science and climate modelling approaches in their analyses.

This study also found in the analysis of further use that the considered transition risk tools seem to expand their analysis into physical risk and alignment areas. A considerable amount of tools is currently developing approaches to be able to assess the trade-off between physical and transition risks, mostly based on the NGFS scenarios.

# 7 Next steps

Based on these findings, the analysis allowed to identify key next steps and general principles to improve financial climate risk analyses for tool provider, tool users and supervisory authorities. The next steps relate to data, scenarios, the tools' general setup, using the tools, and reporting frameworks for tools and tool output.

**Data** availability and reliability are key issues. Climate risk assessments would benefit if the following areas would be improved.

1. Availability and reliability of emission data for all relevant (i.e. material) scopes are key concerns. This holds especially for scope 3 emissions, which are for example important for the automotive industry. As a first step, regulatory authorities might ask tool providers to report the source of the GHG emission data, how data accuracy is assessed (especially for self-reported data e.g. the CDP data), and how providers deal with missing or implausible values. Regulators might also consider to require the use of third party verified data for climate risk assessments, in order to increase accuracy and the quality of risk assessments. Furthermore, regulators could define guidelines on accounting scope 3 emission data, to increase comparability of tool outputs.

2. Forward-looking analyses do not only use scenarios, they ideally also use forward-looking company-level data. Yet, these data inputs are currently scarce (e.g. CAPEX data). Spatial

production asset-level data together with the assets' remaining lifetime, and CAPEX plans, could significantly improve the accuracy of forward-looking risk exposure analysis. Furthermore, data on the share of each business activity and each production asset in firm turnover would be important information to translate emission data into economic data and hence the exposure into potential economic impact. The EU Taxonomy Regulation is expected to improve data availability in this area for listed companies that are subject to the Non-financial Reporting Directive. However, data challenges for private companies still need to be solved. Furthermore, regulators should ensure that the data is easily accessible, for example in open source databases, and processable by tools.

3. Data and business information related to methane emissions and land use, land use change and forestry activities are another key area to be improved. Data on methane emissions is especially important to improve accuracy of analyses for the oil & gas sector, the agricultural sector, and waste management activities.

**Scenarios** are, besides data, the second key component of forward-looking analyses. The following scenario-related points are especially important to improve climate risk assessments.

1. More granular scenarios, differentiating by business activity and by country, would be required. Developing more granular scenarios to achieve the 1.5°C target at the common 66% confidence level would be especially important. The scenarios need to reflect various temperature targets and assumptions on how to achieve the targets, in order to enable tool providers to derive a probability distribution-based output and to compare the difference between different points in time. For example, there might be a significant difference in the energy mix between 2040 and 2050, if emissions peak relatively late and need to decrease at sharper rate afterwards. This would have significant implications on the value or risk of stranding investments in energy generation technologies. In addition, the potential reliance on CCS and NETs (and associated investment needs into these technologies) should be taken into account.

2. There is a need for scenarios, where methane emissions, the agricultural sector, and associated land use, land use change and forestry are reflected at more granular and country-differentiated level. This would be important to better assess climate-related risks in the agricultural sector, including all types of related business activities like for example lifestock, diary and milk, food processing and other. Furthermore, this would enable better analyses of the trade-offs between emissions in sectors other than agriculture and their required need for land for carbon sinks and carbon dioxide removal, and emissions stemming from agricultural production activities.

3. Scenarios reflecting the NDCs by country would need to be updated with new NDC announcments, or when new climate-related policies are introduced at the country level. This is especially important for policies, which define sectoral carbon budgets - and even more so, if these carbon budgets are also allocated over time by climate laws. Reflecting these policies in the scenarios would mean that modellers do not need to choose a sectoral carbon budget allocation approach, which would enhance realistic projections. In turn, this means that regulators might significantly help more realistic climate risk assessments when allocating country emission budgets to sectors and years in their climate policy frameworks. In

line with this consideration, it would be important that tool providers regularly update the scenarios they employ, in order to reflect latest state of the art in climate modelling, and account for changes in climate-related policies, technology and market developments.

**Tool approaches** and services could be further improved by tool providers, in addition to the points on data and scenarios.

1. Tool providers should aim for better reporting of the data and scenario inputs, key assumptions, and the individual modelling steps and depth of risk analysis. In line with enhanced reporting approaches, they should increase public transparency of their models. This would allow tool users to better understand what is being assessed, and increase comparability of data across tools. This is an important aspect for investors, if they use the climate risk metrics as reported by companies to assess the climate risk of their portfolio or investment decisions. Furthermore, this would ease the scientific peer-review of tools, and hence serve as a mechanism to ensure tools reflect the latest state of the research, and increase the quality of the various approaches.

2. Tool providers should be more transparent about key scenario and modelling assumptions, when communicating the tool output. This is relevant to ensure interpretability and comparability of the tool outputs. Furthermore, it would enable tool users to e.g. follow a precautionary approach with early emission peak and low reliance on CCS and NETs, if they want. Related to this aspect, tool providers should try to be scenario neutral, to allow users to reflect their beliefs and preferences in the model; and to generate probability distributions of possible future outcomes.

3. With regards to tool coverage, tool providers might aim to cover more asset classes, risk sources and risk realisations, emissions, and sectors. Mortgages and real assets are still not broadly covered. The same holds for technology, market upstream and market downstream risk sources. Methane emissions and the agricultural sector are also not broadly covered, yet. Furthermore, if the services and financial sector are not assessed by tools, transition risks might be overlooked - at least if one assumes a Paris Agreement-aligned trajectory where all sectors need to decarbonise according to the IPCC. Improving the modelling of mutual risk amplification mechanisms and especially financial amplification mechanisms, including second round macroeconomic and financial market effects, would be another important area of improvement.

**Tool use principles and reporting** are another important aspect to improve climate-related financial risk assessments.

1. Tool users should be aware of the relevance of transition narratives and associated scenario assumptions. It is important to select a narrative that fits to own beliefs and assumptions about future developments, but also to the own risk averseness (Chenet et al., 2019). In addition, best and worst case scenarios should be considered.

2. On the appropriate use of tools, the study found that each risk sources and all considered financial assets are always covered by at least two tools, usually more. This allows tool users to compare the results of different tools, since it can be reasonable to not rely on a single

tool's assessment. Whether the same tool provides converging or diverging risk assessment for the same set of firms will be analysed in a forthcoming study (Bingler et al., 2020). For example, users could use each tool with various scenarios and assumptions to generate a probability distribution of the possible outcomes of each tool, and eventually combine the probability distributions of all tool outputs together. This would mitigate the impact of modelling decisions' on an individual tools' output, and allow for more explicit uncertainty considerations in the analyses.

3. In addition, given the rapidly changing landscape of financial climate risk assessment approaches and available climate scenarios, it is important that tool providers and users constantly update their approaches and analyses. A one-shot analysis of climate risks is not meaningful. It hinders a better understanding of the underlying drivers and assessments can be quickly outdated, due to real-world changes, tool improvements and scenario updates. This suggests that it would be beneficial for a sound consideration of climate-related financial risks in financial institutions, that supervisory authorities require regular reporting about climate risk exposure and risk mitigation activities undertaken by the financial institutions. The results of the assessments should be reported in annual filings, in order to inform investors and other stakeholders on the progress of managing the risks, and to provide access to the metrics required for the stakeholders' own risk assessments. This should ideally be done in line with the TCFD recommendations. It is furthermore important that the key scenario and modelling assumptions are reported alongside the tool output, in order to ease interpretability.

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# Appendix

## A Tool descriptions and analyses

Since information as reported in the next Sections is to large extent private, the following Sections rely on the accuracy of tool providers' self-reported information and publicly available tool documentations.

## 2 Degrees Investing Initiative - PACTA

| | |
|---|---|
| **Full name** | Paris Agreement Capital Transition Assessment (PACTA) |
| **Short name** | 2DII |
| **Owner** | 2 Degrees Investing Initiative |
| **Developer** | Consortium led by 2 Degrees Investing Initiative, supported by UNPRI |
| Partners | WWF, Frankfurt School of Finance & Management (Frankfurt School), Kepler-Cheuvreux, Climate Bonds Initiative, CDP, University of Zurich, Carbon Tracker Initiative, The CO-Firm, University of Oxford |
| **Access** | Public, free access |

Table 14: Summary 2 Degrees Investing Initiative - PACTA

Model Documentation: See Hyperlink PACTA Online Documentation

### Key characteristics (Based on self-description)

The PACTA tool covers equity and bond issuers and is based on analysis of companies' investment and production plans in both high-emissions activities and low-carbon solutions. The results are then compared with technology and energy mix which would be consistent with the trajectory towards a given climate scenario. The output of the tool is a "technology exposure gap" showing how investment and production plans are aligned with a given climate scenario. In particular, the tool helps answering three research questions:[33]

1. What is the exposure to climate relevant sectors and technologies of a given portfolio?
2. How does the exposure to climate relevant technologies of the companies in the portfolio change over time? Does the climate transition risk for these companies increase or decrease over time?
3. How do the aggregated CAPEX plans (of the clients) align with climate scenarios?

The objective of the PACTA assessment framework is to measure the alignment of financial portfolios with 2°C decarbonization pathways. Specifically, the framework quantifies a financial portfolio's exposure to a 2°C benchmark in relation to various climate-related technologies. The result is thus a misalignment indicator that measures the extent to which current and planned assets purchases, production profiles, investments, and GHG emissions are aligned with a 2°C trajectory. The model used does not follow pre-defined macroeconomic trends or shocks, but rather creates a "translation software" that maps forecasted macroeconomic trends and shocks into financial portfolios impacts. Thus, it does not rely on developing these economic trends themselves and can be used to test any macroeconomic assumption (2dii, 2016). In the following the key modeling principles are briefly summarized (See Hyperlink: PACTA Online Documentation):

- The model calculates the expected benchmark exposure for each technology in the specific asset class by taking the current exposure in the respective asset class and geography and

[33]For the Swiss climate compatibility test offered at the moment to all Swiss pensions funds, insurances, banks and asset managers, PACTA also provides a real estate/mortgage module for all Swiss buildings as add on. The focus is on alignment; it will also be open-source available in the future. It was developed by Wüest Partner AG and commissioned by FOEN.

adding the trend line as defined in the scenario (e.g. the IEAs 2°C compatible sustainable development scenario). The build-out percentages take a simple "market share principle" under which the companies in the investable universe are assumed to adjust production capacity in line with the scenario, consistent with their market share;

- The model assesses the scenario alignment of financial portfolios with a 5-year time horizon/forecast period. The time horizon is limited to the time horizon of capital expenditure planning for which data can be tracked at a meaningful level. While this time horizon may differ across sectors, a homogeneous time horizon is taken to allow for the comparability of results;

- The model applies traditional financial accounting principles; notably the equity share principle is followed where possible (i.e. 1% ownership of a company implies 1% ownership of assets). Where data is not available, 100% of the ownership is allocated to the majority owner.

**Model setup**

***Output metrics*:**

- Technology or Sector Exposure (% of AUM or USD);
- Deviation as % (from climate alignment);
- Potentially: Climate pathway (temperature range) at Technology, Sector, Emission intensity per unit of production level (per sector).

Outputs can be used as input into risk models or other existing structures.

***Output format*:**

- PDF Report (soon as customizable HTML or PDF reports including stakeholder specific texts – Q2 2020);
- Excel file (.csv) with output data, charts to display the results (downloadable as .png).

***Risk indicators*:**

- Economic climate risk indicators: Emission intensity - tons of $CO_2$ per sector-dependent unit of production (e.g. $CO_2$ per tons of cement or number of cars produced); Absolute emissions (e.g. at full operating capacity);
- Further indicator: Production capacity vs. scenario compatible production capacity (e.g. MW in the power sector, number of cars, barrels of oil, etc.);
- Peer-comparisons analysis of indicators is available.

**Coverage**

***Transition risk sources*:**

- Policy:
  - Smooth - Online standard setting IEA scenarios;
  - Schock - Online setting under development (project IPR inevitable policy response).
- Market upstream: Scenario-neutral, hence adaptable;

- Market downstream: Scenario-neutral, hence adaptable;
- Technology: Scenario-neutral, hence adaptable;
- Other: Scenario-neutral, hence adaptable.

***Sectors*:** Most emission intensive sectors are included:

- Coal – mining;
- Oil and gas – exploration and production;
- Utilities, Manufacturing – energy intensive industries such as steel and cement;
- Manufacturing – automobile;
- Transportation and Logistics – air, shipping.

***Countries*:** World. Each country is available in the underlying production capacity databases to reflect the scenario granularity.

***Emissions*:** Sector-dependent.

***Analysis horizon and time steps*:** By default, 1-year steps within 5 years, but flexible.

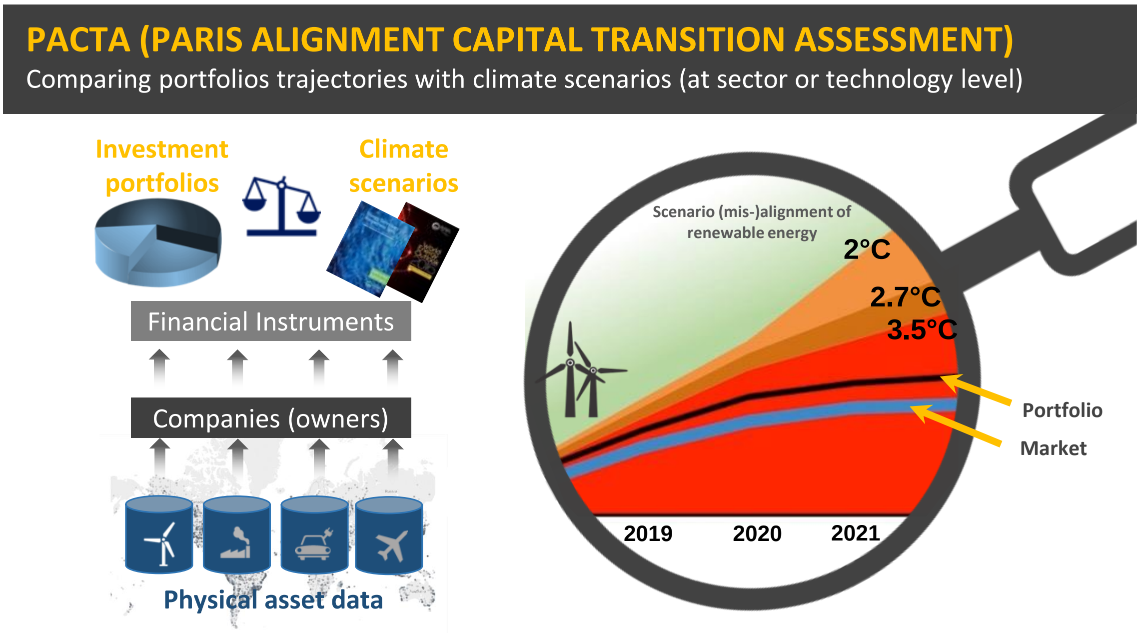


Figure 11: Model overview 2 Degrees Investing Initiative - PACTA, *Source*: Presentation "Climate Scenario Analysis for Investment Portfolio". Outputs of the 2Dii-led, EC-funded projects: Sustainable Energy Investment Metrics (H2020), Energy Transition Risks (H2020), and Paris Agreement Capital Transition Assessment (LIFE), and Investor Energy-Climate Toolkit (H2020).

| Criteria-based tool analysis | | 2DII |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | x | Code publicly available on Github |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Data sources available online in the model documentation. Depending on the sector, third party verified sources are combined with asset level data. Tool not based on emissions, but emissions are calculated. |
| b) Third party verified | (x) | Does not rely on emission data, as emissions are directly calculated by 2DII, based on physical asset-level data |
| c) Missing data strategy explained | x | |
| **3. Science-based approach** | | |
| a) Scientific references | x | The SEI Metrics project - which is the basis for PACTA - was developed together with academia and also published in academic journals |
| b) Peer-reviewed | x | |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Scenario-neutral, IAMC 1.5°C scenario & IPR scenario integrated in 2020 |
| b) Country-differentiated | (c) | Scenario-neutral, hence adaptable |
| c) Sector-differentiated | x | |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | 80-85 % of global emissions are covered by the PACTA sectors, a materiality assessment is currently under development (expected in Q2 2020) |
| b) Expected GHG emissions | x | Main measure for the forward-looking analysis |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | n/a | Not relevant for tool, since it stops before (alignment tool and risk exposure; no risk quantification) |
| b) Peers performance, competition | n/a | " |
| c) Cost pass-through | n/a | " |
| **7. Adaptability** | | |
| a) Input substitution | n/a | " |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Main measure for the forward-looking analysis |
| **8. Economic impact** | | |
| a) Economic losses and gains | n/a | " |
| b) Macroeconomic development | n/a | " |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | n/a | " |
| b) Financial market amplifications | n/a | " |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Detailed model structure and assumptions documented, see "Model Documentation" |
| b) Assumptions-based output communication | (x) | The report provides further information about the assumptions, key features, modelling choices, etc.; Online documentation section on caveats/notes for interpreting the results |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | Scenario-neutral |
| b) Scenario-neutral (various risk realisations) | x | Senario-neutral: Any scenario can be used if appropriately formatted; Default online: IEA; Also available: WEO, ETP , Greenpeace; IAMC and IPR scenarios in 2020 |
| c) Probability distribution input (timing) | dvp | Simple stress-testing tool version available online; update to select shock materialization point in time and duration is under development (expected in Q4 2020) |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | (c) | Geoloc data is available, hence overlaying risk maps with assets in the covered sector combination is possible |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | x | |
| b) Financial institution impact analysis | - | Action-based impact method for financial institutions under development |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 15: Analysis 2 Degrees Investing Initiative - PACTA

## Battiston, Monasterolo and Mandel - CLIMAFIN

| | |
|---|---|
| **Full name** | CLIMAFIN - Climate Finance Alpha |
| **Short name** | CFIN |
| **Owner** | Stefano Battiston, Antoine Mandel, Irene Monasterolo |
| **Developer** | *same as owner* |
| **Access** | Public model, customized analyses at individual costs |

Table 16: Summary Battiston, Monasterolo and Mandel - CLIMAFIN

Model Documentation: See Hyperlink CLIMAFIN Online Documentation, Battiston et al. (2019).

### Key characteristics (Based on self-description)

CLIMAFIN combines the analysis of large datasets on financial and industrial relationships with new financial network algorithms to estimate the propagation of climate shocks towards firms and the resulting impacts on financial assets (See Hyperlink CLIMAFIN Online Documentation). The CLIMAFIN tool embeds climate scenarios adjusted financial pricing models (for equity holdings, sovereign and corporate bonds), and climate scenarios conditioned risk metrics (such as the Climate Spread and the Climate Value-at-Risk). This allows to introduce forward-looking climate risk scenarios in the valuation of counterparty risk, in the probability of default and losses on investors' portfolios.

### Model setup

***Output metrics*:**

- Expected loss;
- Value-at-risk;
- Conditional value-at-risk (USD);
- Climate-induced change in default probability: Climate-spread (induced change in yield).

***Output format*:**

- Spreadsheet;
- Customized report.

***Risk indicators*:**

- Climate-adjusted financial risk indicator: Earnings before interest taxes depreciation and amortization (EBITDA) per business segment;
- Segment exposure to climate policy.

### Coverage

***Transition risk sources*:**

- Policy: Shock, adaptable to users' beliefs and expectations;
- Market upstream: Shock, adaptable to users' beliefs and expectations;

- Market downstream: Shock, adaptable to users' beliefs and expectations;
- Technology: Shock, adaptable to users' beliefs and expectations;
- Other: Any shock, adaptable to users' beliefs and expectations.

***Sectors***: Climate-policy relevant sectors as defined in Battiston et al. (2019).

***Countries***: World.

***Emissions***: Material emissions, depending on application case

***Analysis horizon and time steps***: Fully flexible.

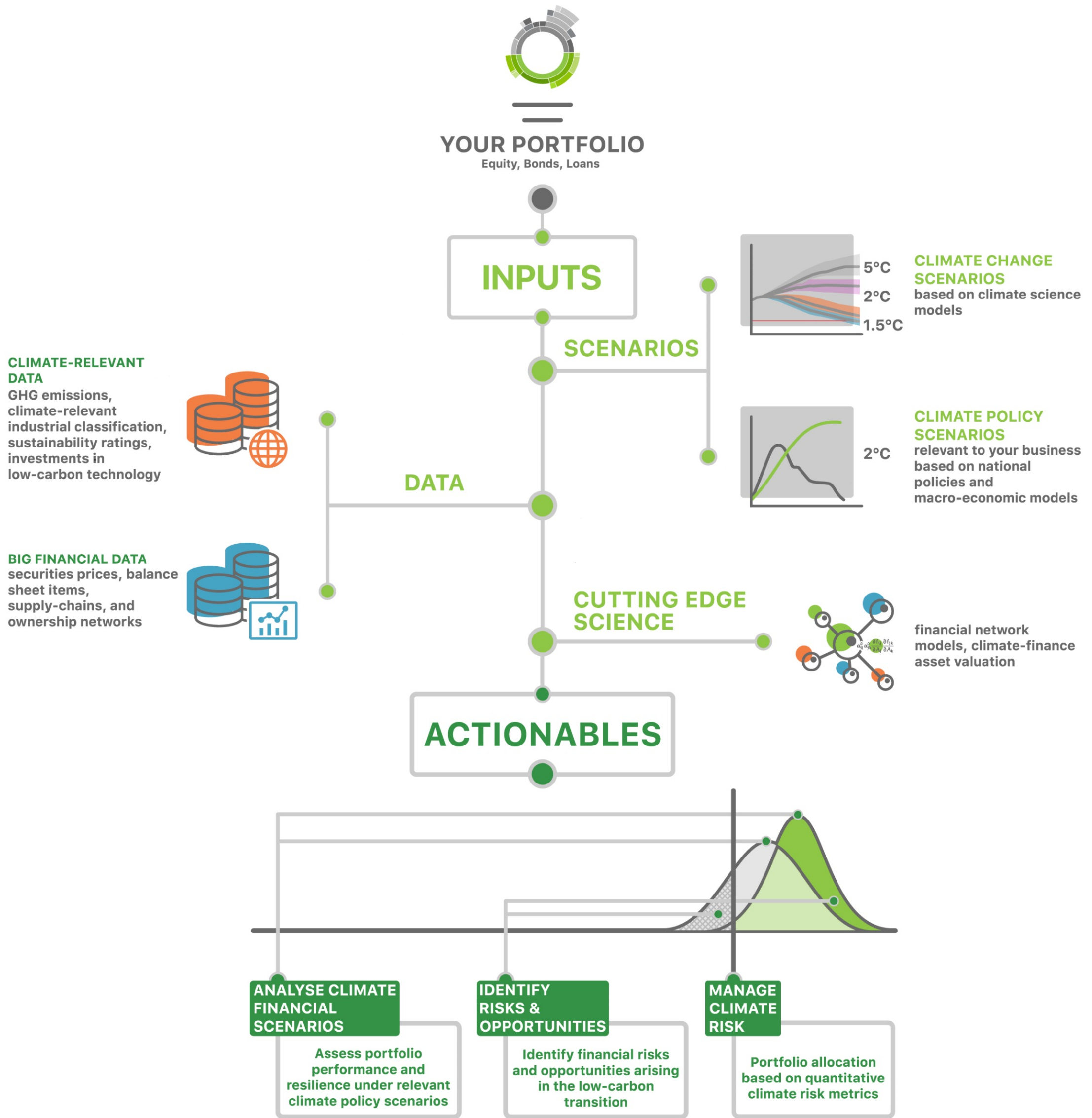


Figure 12: Model overview Battiston, Monasterolo and Mandel - CLIMAFIN, *Source*: See Hyperlink CLIMAFIN Online Documentation.

| Criteria-based tool analysis | | CFIN |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | (x) | Available from the authors upon request, for scientific use |
| b) Study questionnaire completed | (x) | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Various sources depending on application case |
| b) Third party verified | (x) | Various sources |
| c) Missing data strategy explained | (x) | Depending on application case |
| **3. Science-based approach** | | |
| a) Scientific references | x | See above "Model Documentation" |
| b) Peer-reviewed | x | See above "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | |
| b) Country-differentiated | x | |
| c) Sector-differentiated | x | |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Depending on application case, materiality can be ensured |
| b) Expected GHG emissions | - | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | Loss/gains in profits covered |
| b) Peers performance, competition | x | Transition-induced change of within-sector competition taken into account |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | - | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, increase in production costs via increase in input prices; Increase in profits, decrease in production costs (technology-related fix costs) |
| b) Macroeconomic development | x | Transition-induced change in economy's sectoral composition; transition-induced change in trade patterns |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | (c) | Scenario-adaptable, hence it should be feasible if one considers a scenario that models mutual risk amplification mechanisms |
| b) Financial market amplification | x | Financial amplification, propagation of shocks through financial interlinkages: Network effects, revision of investor expectations / sentiment, balance sheet effects |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Available from the scientific literature. Full list of references: See model homepage `climexproject.eu/team-members/#research` |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | Default: Business as usual, with IEA assumptions |
| b) Scenario-neutral (various risk realisations) | x | Default: IEA |
| c) Probability distribution input (timing) | x | User- and scenario-specific |
| d) Probability distribution output (values) | (c) | Can do if run model several times |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | (c) | Can be provided if data is available for assets under consideration |
| b) Trade-off physical-transition risks | (c) | Scenario-adaptable, hence it should be feasible if a meaningful trade-off scenario is available |
| **Climate targets** | | |
| a) Alignment assessed | x | Risk output is also alignment indicator |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 17: Analysis Battiston, Monasterolo and Mandel - CLIMAFIN

## Cambridge Econometrics - E3ME-FTT-GENIE

| | |
|---|---|
| **Full name** | E3ME-FTT-GENIE |
| **Short name** | CAME |
| **Owner** | Cambridge Econometrics |
| **Developer** | Cambridge Econometrics, University of Exeter, Open University |
| **Access** | Public model, customized analyses at individual costs |

Table 18: Summary Cambridge Econometrics - E3ME-FTT-GENIE

Model Documentation: See Hyperlink E3ME Online Documentation, Mercure et al. (2018).

### Key characteristics (Based on self-description)

The model is a macroeconomic simulation model with extensions to consider technology adoption and climate impacts. The inputs are the policy shocks which form the scenarios, and the model provides estimates of impacts of the policies on the global economy (disaggregated by region and sector), energy consumption and the take up rates of new technologies, and emissions – which can be used to generate an estimate of mean global temperature change

The model is focused on the real economy, but there financial flows between different institutional sectors (government, households, banking sector, external sector) are included. The model can also track financial flows between NACE economic sectors, although data here is more limited.

### Model setup

***Output metrics*:**

- Macroeconomic and sectoral economic impacts – volumes and prices, split to 43 sectors;
- Energy consumption by 22 sectors and 12 fuels;
- Sectoral $CO_2$ emissions, uptake of key technologies in the power, road transport, steel and household heating sectors.

***Output format*:** Excel, customizable

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions, converted to temperature change in the GENIE model; Emission intensity (per unit of output).

### Coverage

***Transition risk sources*:**

- Policy:
  - Smooth, shock; Adaptable to users' beliefs and expectations;
  - Wide range of policies, both price-based and regulatory impacts, and measures to promote the uptake of clean technologies;
- Market upstream: Smooth, shock; Adaptable to users' beliefs and expectations;

- Market downstream: Smooth, shock; Adaptable to users' beliefs and expectations;
- Technology: Smooth, shock; Adaptable to users' beliefs and expectations.

***Sectors***: All (see `https://www.e3me.com/features/dimensions/`).

***Countries***: World, 61 regions (see `https://www.e3me.com/features/dimensions/`).

***Emissions***:

- $CO_2$ (scope 1-3);
- Methane ($CH_4$), Nitrous oxide ($N_2O$), Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), Hydrofluorocarbons (HFCs) (scope 3).

***Analysis horizon and time steps***: 1-year time steps, model runs up to 2100, net-zero emissions depend on scenario employed.

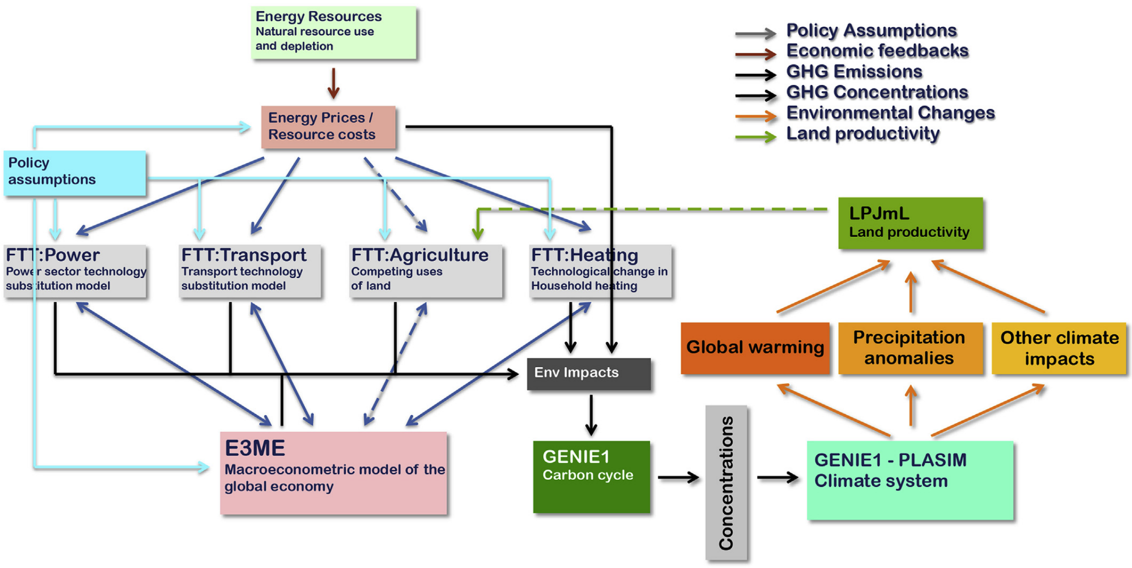


Figure 13: Model overview Cambridge Econometrics - E3ME-FTT-GENIE, *Source*: Mercure et al. (2018).

| **Criteria-based tool analysis** | | CAME |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | (x) | The E3ME source code is restricted access (and includes some third party code), the FTT models are open access (upon request) |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Emission data estimated by third party provider (EDGAR database) |
| b) Third party verified | - | Provided data are assumed to be accurate |
| c) Missing data strategy explained | (x) | Assessment available only when no missing data |
| **3. Science-based approach** | | |
| a) Scientific references | x | See above "Model Documentation" |
| b) Peer reviewed | x | See above "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Own scenarios based on set of policy inputs, matched on various temperature goals. Different macro and sectoral economic outcomes for each scenario |
| b) Country-differentiated | x | User-specific |
| c) Sector-differentiated | x | Modeling carried out at sectoral level. User-specific and sector-specific settings |
| **5. Exposure** | | |
| a) Current GHG emissions | x | See above "Emissions" |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | Quantifies profit losses and gains, sector-specific |
| b) Peers performance, competition | - | |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | - | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Losses in profits, revenues (decrease in demand, increase in wholesale prices, loss of capital stock, indirect impacts via health), increase in production costs (increase in input prices, increase in fix and variable costs); Gains: Increases in profits, revenues (increase in demand, lower wholesale prices than competitors), decrease in production costs (decrease in input prices, decrease in fix and variable costs), sector-specific |
| b) Macroeconomic development | x | Change in economy's sectoral composition and in trade patterns; Impacts on technology and potential output and on share of potential output realized; sector-specific |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | x | Policy exogenous but strong positive reinforcing technology feedbacks leading to path dependence in the projections – especially in the FTT bottom-up technology models |
| b) Financial market amplification | dvp | Network effects in work for the UK government currently under investigation |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Transparent underlying models, assumptions | x | Full documentation available on the model website `www.e3me.com` |
| b) Assumptions-based output communication | (x) | Users select assumptions themselves, degree of transparency depends on how users present their analysis output |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | User-specific, range of default reference scenarios; usually one of the IEA scenarios, but can be any scenario |
| b) Scenario-neutral (various risk realisations) | x | User-specific. Own scenarios are developed, based on a set of policy inputs, which could match to a range of different temperature goals but have different macro and sectoral economic outcomes |
| c) Probability distribution input (timing) | x | User-determined point in time |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | x | Aggregate damage functions, but being revised to include direct feedbacks to the model's equations at sectoral level, e.g. for productivity indicator / analysis output |
| b) Trade-off physical-transition risks | dvp | Feasible in future specification |
| **Climate targets** | | |
| a) Alignment assessed | (x) | Can be derived from output |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 19: Analysis Cambridge Econometrics - E3ME-FTT-GENIE

## Cambridge Institute for Sustainability Leadership - ClimateWise

| | |
|---|---|
| **Full name** | ClimateWise Transition risk framework |
| **Short name** | CISL |
| **Owner** | University of Cambridge Institute for Sustainability Leadership |
| **Developer** | ClimateWise |
| **Access** | Public, free access |

Table 20: Summary Cambridge Institute for Sustainability Leadership - ClimateWise

Model Documentation: See Hyperlinks CISL Online Report, CISL Online Guide

### Key characteristics (Based on self-description)

The framework focuses on infrastructure investments and can be applied to an array of global infrastructure asset types. The tool follows the general scheme: Financial driver analysis → Transition scenario analysis → Portfolio risk and opportunity exposure → [optional: Asset impact identification] → [optional: Financial modeling analysis] → Tool output. The framework is set out in three steps, which can be used independently or combined to explore transition risks and opportunities (CISL, 2019a). Each of the three steps highlights practical actions investors might take in order to manage risks and capture opportunities:

- Step 1: Portfolio risk and opportunity exposure. This step allows investors to identify the material financial impacts from transition risks across a large portfolio, by applying the Infrastructure Risk Exposure Matrix. This step helps to assess potential exposure to transition risk across a breadth of asset types, geographies, climate scenarios and time frames.
- Step 2: Asset impact identification. This step allows investors to assess the financial impact from the low carbon transition at an asset-by-asset level, which provides insights on ways to improve asset resilience. Risks vary considerably between assets of the same type, depending on their geography, carbon intensity, technology (for example solar versus wind) and competitive positioning in the local market. Depending on an investor's portfolio size and risk appetite, the Asset Impact Identification Methodology can be re-applied asset-by-asset to an entire portfolio, or to the most exposed assets identified by overlaying Infrastructure Risk Exposure Matrix. Additionally, stress testing of the portfolio under different time frames and scenarios will produce a more holistic understanding of transition risk and opportunity.
- Step 3: Financial modeling analysis. This step allows investors to incorporate the potential impacts of transition risk directly into their own financial models. This is done by integrating the financial drivers identified in Steps 1 and 2 into investors' own in-house financial models.

### Model setup

***Output metric*:** Percentage change in financial drivers, scaled up to sector and portfolio summary, due to climate scen ario.

***Output format*:** Excel file with heat map of the output metrics. Results can then be summarized as pie charts for specific portfolio.

***Risk indicator*:**

- Financial climate risk indicator: Comparison of impact of financial drivers on assess risk exposure of specific sectors and geographies due to climate scenarios – the tool provides a rating of minimal, low medium or high risk or opportunity.

**Coverage**

***Transition risk sources*:**

- Policy: Smooth; Emerging policy and legal requirements from World Bank, government ETS, etc; Adaptable to users' beliefs and expectations;
- Market upstream: Smooth; Market and technology shifts from IEA WEO and ETP, eg transport costs; Adaptable to users' beliefs and expectations;
- Market downstream: Smooth; Market and technology shifts from IEA WEO and ETP; Mounting reputation pressures and investor sentiment; Adaptable to users' beliefs and expectations;
- Technology: Smooth; Adaptable to users' beliefs and expectations;
- Other: Smooth; Reputation impacts and investor sentiment may be considered as market downstream or separately.

***Sectors*:**

- Power assets: coal power plants, gas power plants, nuclear power plants, renewables;
- Fuel infrastructure: oil pipelines and midstream infrastructure, gas pipelines and midstream infrastructure;
- Public buildings;
- Utilities;
- Transportation and Logistics: surface, air, shipping;
- Information and communication
- Water supply, sewage, waste management.

***Countries*:** USA, EU, India.

***Emissions*:** n/a.

***Analysis horizon and time steps*:** Investment time frames typically vary: banks (five years), infrastructure investment companies (10 to 15 years), governments considering asset life (20 years or more). While the framework can be adapted to cover any year (as scenario data sets typically cover a year-by-year basis), the Infrastructure Risk Exposure Matrix focuses on 2020, 2030 and 2040 (upcoming: 2025) to cover as broad a range of investment horizons as possible (CISL, 2019a).

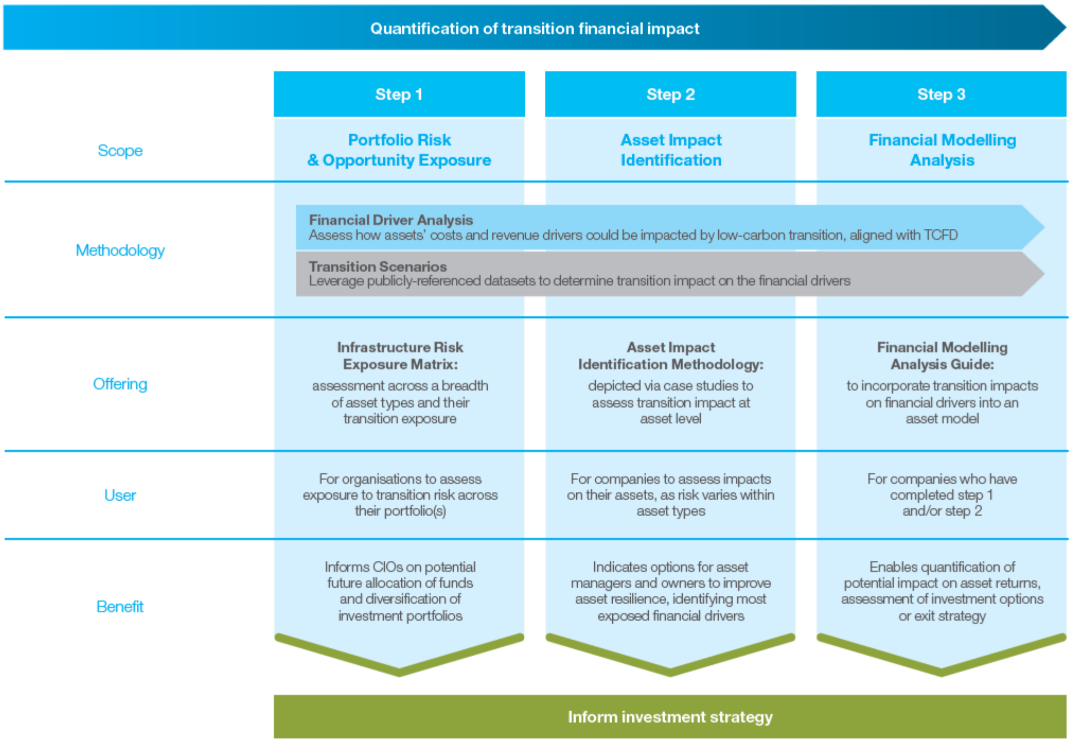


Figure 14: Model overview Cambridge Institute for Sustainability Leadership - ClimateWise. *Source*: CISL (2019a).

| **Criteria-based tool analysis** | | CISL |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | (x) | |
| b) Third party verified | (x) | |
| c) Missing data strategy explained | (x) | Gaps in scenario data supplemented with other publicly referenced sources |
| **3. Science-based approach** | | |
| a) Scientific references | x | See above "Model Documentation" |
| b) Peer-reviewed | (x) | See above "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | - | Consider 2°C and 3-4°C |
| b) Country-differentiated | x | Sources and impact considered for India, EU and USA |
| c) Sector-differentiated | x | Risk Exposure Matrix allows risk weighting on the estimated relative contribution of each financial driver to the financial performance of each asset type or sub-sector by country |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | Infrastructure Risk Exposure Matrix by sector, based on scenario analyses. GHG emission not main consideration for the choice of assets types and jurisdictions |
| b) Expected GHG emissions | - | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | - | |
| b) Peers performance, competition | - | |
| c) Cost pass-through | - | |
| **7. Adaptability** | | |
| a) Input substitution | - | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | - | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in revenues (decrease in demand, increase in wholesale prices), increase in production costs (increase in input prices, production technology-related fix and variable costs); Gains: Increase in revenues (increase in demand, lower wholesale prices than competitors), decrease in production costs (decease in input prices, decrease in production-related fix and variable costs) |
| b) Macroeconomic development | (x) | Sector-dependent |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | - | |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Baseline assumptions and scenarios underlying this tool could be found in CISL (2019a). Users could follow the step by step methodology (CISL, 2019b) in order to have better interpretation of the output |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (x) | Range of scenarios to choose from, IEA, IPCC and others. Based on IEA WEO Current Policies scenario, ETP 6DS scenario for transport. IEA WEO states the baseline is roughly in line with IPCC (RCP8.5) scenario of 3.7°C (mean) global warming by 2100 |
| b) Scenario-neutral (various risk realisations) | (x) | Range of scenarios to choose from: Paris Agreement (NDCs) and 2°C scenario; Provider: IEA and others |
| c) Probability distribution input (timing) | (x) | Time of risk materialization (stated in the comment section) affects scores for risk/ opportunities in different time points (e.g. carbon pricing policy reforms or projected technology cost drop in 2030); Framework adaptable to include shocks or adjust the time of risk materialization by changing the risk/ opportunity scores in different time point according to reference sources and expectations |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | (x) | Physical risk module available; possible analysis of financial drivers included within the infrastructure risk exposure matrix |
| b) Trade-off physical-transition risks | dvp | |
| **Climate targets** | | |
| a) Alignment assessed | (x) | The analysis for each scenario identifies impact of sub-sector's alignment implicitly |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 21: Analysis Cambridge Institute for Sustainability Leadership - ClimateWise

## Carbone 4 - Carbon Impact Analytics

| | |
|---|---|
| **Full name** | Carbon Impact analytics (CIA) |
| **Short name** | CAR4 |
| **Owner** | Carbon4 Finance |
| **Developer** | Carbone 4 |
| **Access** | Public, paywall, fixed price and customized options |

Table 22: Summary Carbone 4 - Carbon Impact Analytics

Model Documentation: Carbone4 (2018).

### Key characteristics (Based on self-description)

Carbon Impact Analytics has been developed with the aim of answering to the following needs of asset managers (Carbone4, 2018):

- Measure GHG emissions induced by investments on the complete scope of underlying firms' impact;
- Measure how underlying firms are contributing to and / or compatible with decreasing worldwide carbon emissions;
- Evaluate how the carbon impact of underlying firms will evolve in the coming years;
- Enable reporting on the carbon impact of portfolios and piloting of investment strategy.

Carbon Impact Analytics measures the carbon footprint of companies using a detailed bottom-up approach. Each asset is analyzed individually and selectively before consolidating the results at portfolio level. This methodological choice makes it possible to compare the carbon performance of companies in the same sector. This method allows to distinguish between the best and worst players within sectors. Moreover, Carbon Impact Analytics differentiates "high stakes" and "low stakes" sectors, and provides specific insights for "high stakes" sectors, with tailored calculation principles for each of them. The approach adopted is based on data collection (tons, km, MWh. . . ), which is then used to calculate induced emissions and emissions savings. It includes an analysis of the company's strategy, green CAPEX and targets to provide a forward looking assessment. This allows for a comparison with scenarios (IEA ETP) and to assign a global score (from A to E).

### Model setup

***Output metrics*:**

- Quantitative: induced emissions scope 1-3 ($tCO_2$), emission savings scope 1-3 ($tCO_2$), financial carbon intensity ($tCO_2$/MEUR of investment or revenue);
- Qualitative: forward-looking company strategy (from ++ to –), overall rating and alignment with 2°C trajectories (from A to E);
- Energy- and sector specific indicators: Green and brown share, energy consumption / production mix, fossil fuel reserves etc. (%Revenue, MWh, MMBOE etc.).

***Output format*:**

- PDF format;
- Excel file or CSV, online plateforme, API.

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions, assessed as $CO_2$ emissions emitted directly or indirectly through the company's activities; Emission intensity, assessed using enterprise value and turnover; Production capacity emissions, namely: $tCO_2$/MWh, $tCO_2$ /t, $tCO_2$ /km...;
- Peer comparison, namely: overall score for each company calculated according to the score of the different sectors of a company and weighted according to the turnover;
- Transition readiness, namely: avoided emission, green share, strategic orientation;
- Other: brown shares.

**Coverage**

***Transition risk sources*:**

- Policy: Smooth, shock;
- Market upstream: Smooth, shock;
- Market downstream: Smooth, shock;
- Technology: Smooth, shock; Technology-agnostic, assess if technologies enable global and life-cycle emissions reduction;
- Other: -

***Sectors*:** All, yet focus on "high stakes" sectors:

- Energy sectors: the most pertinent challenge of energy companies is to diversify their energy mix, favoring more low-carbon sources, and to reduce direct emissions;
- Suppliers of equipment with a low-carbon potential: the challenge of these companies is to innovate, and to make these innovations available on the market;
- Carbon intensive sectors: the challenge of these companies is to reach "climate operational performance" by implementing energy-efficient and low-carbon solutions;
- Financial sector: the challenge of these companies is to reallocate the capital from carbon intensive assets to assets contributing to the low-carbon transition.

***Countries*:** World.

***Emissions*:** CO2, $CH_4$, $N_2O$, Ozone ($O_3$), CFCs, HCFCs and HFCs (all scope 1-3).

***Analysis horizon and time steps*:** 1-year time steps.

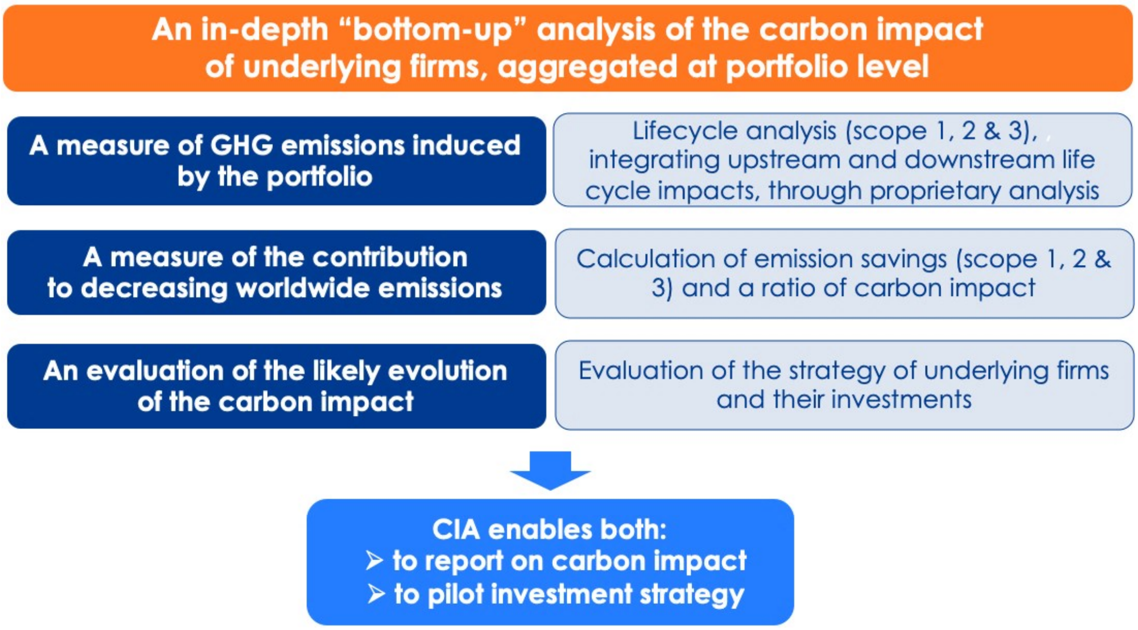


Figure 15: Model overview Carbone 4 - Carbon Impact Analytics. *Source*: Carbone4 (2018)

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| **Criteria-based tool analysis** | | CAR4 |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Private, tool owner only |
| b) Study questionnaire completed | (x) | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Assessment of copes 1, 2 and 3 emissions. If scopes 1+2 emissions are closed to reported emissions, reported emissions are used; Scope 3 is always calculated by analysts, based on activity (production) data of the company |
| b) Third party verified | (x) | Use own method to verify reported data |
| c) Missing data strategy explained | x | Own calculation when missing data; Data accurancy: bottom-up methodology data instead of top-down (presumably more accurate); can differentiate actors within a same sector |
| **3. Science-based approach** | | |
| a) Scientific references | (x) | Use IEA ETP scenarios |
| b) Peer-reviewed | - | |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | - | Solely based on IEA 2DS, hence only 2°C covered |
| b) Country-differentiated | (x) | Depending on the sectors, global emission savings calculated at markets level (geographic zones) |
| c) Sector-differentiated | x | |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Differentiate high, medium and low stakes by sector; Explicit analysis of relevant scopes |
| b) Expected GHG emissions | n/a | mainly carbon impact tool |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | n/a | " |
| b) Peers performance, competition | n/a | " |
| c) Cost pass-through | n/a | " |
| **7. Adaptability** | | |
| a) Input substitution | n/a | " |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Qualitative rating (++ to –) based on the evaluation of: company's low-carbon CAPEX and low-carbon R&D; The strategy and positioning of the firm regarding the low-carbon transition; The GHGs reduction targets of the firm |
| **8. Economic impact** | | |
| a) Economic losses and gains | n/a | mainly carbon impact tool |
| b) Macroeconomic development | n/a | " |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | n/a | " |
| b) Financial market amplification | n/a | " |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | (x) | Based on IEA ETP scenarios |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | - | Starting point: status quo, trend: IEA ETP 4DS |
| b) Scenario-neutral (various risk realisations) | - | IEA ETP 2DS and qualitative reasoning (combination of current and future performance) |
| c) Probability distribution input (timing) | n/a | No risk tool |
| d) Probability distribution output (values) | n/a | |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | (x) | Covered through a tool called Climate Risk Impact Screening; separate analysis output |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | x | |
| b) Financial institution impact analysis | x | Overall goal of the tool |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 23: Analysis Carbone 4 - Carbon Impact Analytics

## ISS ESG - Portfolio Climate Impact Report and Raw Data

| | |
|---|---|
| **Full name** | Portfolio Climate Impact Report and Raw Data (automatic online report of ISS ESG available via Datadesk, raw data available off the shelf and on bespoke basis) |
| **Short name** | ISSE |
| **Owner** | ISS ESG, the responsible investment arm of Institutional Shareholder Services Inc. |
| **Developer** | *same as owner* |
| **Access** | Public, paywall, fixed price and customized options |

Table 24: Summary ISS ESG - Portfolio Climate Impact Report and Raw Data

Model Documentation: See Hyperlink ISS ESG Online Documentation, Busch et al. (2018).

### Key characteristics (Based on self-description)

The Portfolio Climate Impact Report provides a simple interface that generates a report containing carbon and climate related information delivered by ISS ESG's research teams. The report supports the upload of equity and fixed income portfolios – individually or in bulk - and is designed to support investors who want to comply with key disclosure frameworks, such as the TCFD (ESG, 2019b). Climate Impact Report provides for both equity and fixed income strategies detailed analyses of transitional climate risks covering fossil fuel reserves and renewable energy assets, as well as physical climate risks linked to the sector and geographic exposure of the portfolio holdings. The report also includes a 2°C climate scenario assessment as well as the Carbon Risk Rating, a comprehensive assessment of the climate-related performance of companies. The latter is based on over 100 mainly industry-specific indicators and a carbon risk classification at the industry and sub-industry levels. The Carbon Risk Rating includes the Carbon Performance Score, indicating how a company is managing its industry-specific climate risks, not just in production but also in its supply chain and product portfolio. Moreover, ISS ESG disposes of the Industry Carbon Risk Classification, which categorizes a company's exposure to carbon risk as a result of its business activities (ESG, 2019a).

Complementing the standardized report, data is available on ISS ESG's online platform Datadesk on companies' compliance with climate disclosure standards, governance, strategy, risk managment and metrics and targets. Additionally, on a bespoke basis, company specific financial impacts can be assessed based on ISS' proprietary EVA ("economic added value") methodology.

### Model setup

***Output metrics***:

- Portfolio GHG emissions scope 1-3;
- Transition risk analysis including an analyst-driven carbon risk rating, fossil reserves, energy production in green and brown metrics (incl. comparison to 2DS climate pathway), controversial business practices such as arctic drilling, fracking, tar sands etc;
- Physical risk analysis on acute and chronic risks;

- Scenario analysis on 2, 4 and 6°C of warming.

***Output format*:**

- 10 page report in PDF format with output metrics figures and graphs;
- Excel sheet with all underlying data for all screened and covered assets;
- Climate Analysis on nearly every asset class, Climate Strategy Development, Climate Reporting Services (including full TCFD reporting) Advisory Services and Voting Services are also available.

***Risk indicators*:** In the automated report:

- <u>Economic climate risk indicators</u>: Absolute emissions, assessed against the following metric: $tCO_2e$ Scope 1, 2 and 3; Emission intensity, using the following metric: $tCO_2e$ normalized by Market Cap and ownership ("per money invested") , $tCO_2e$ normalized by adjusted Enterprise Value and ownership ("per money invested" – for fixed Income and balanced portfolios), $tCO_2e$ normalized by revenue and ownership ("per money invested"), $tCO_2e$ normalized by revenue and portfolio weight (Weighted Average Carbon Intensity- WACI);
- Production capacity emissions, namely: % installed capacity for utilities, power generation exposure, fossil fuel reserves volume per type, potential emissions from fossil fuel reserves per type;
- Transition readiness, namely: Carbon Risk Rating, based on in-depth company analysis including a view on climate risks and opportunities as well as products and services: scale 0-100.

In the database outside the report, there are many more granular datapoints available in the "Energy and Extractives" dataset:

- Peer comparison, namely: Peers are defined based on ISS ESG's own carbon tilted sector classification system. Comparison takes place based on emissions per revenue, emissions per money invested and – where available – per unit of output;
- Other: ISS ESG has up to 400+ climate-linked datapoints per company of which many are reflected in the automatic report.

Additional information is available via the online tool DataDesk in form of datasets. This includes the "Environmental & Quality Score" dataset with hundreds of indicators on climate strategy, governance, risk management and metrics and targets as well as climate-linked norms violations, avoided emissions per company versus a baseline etc.

**Coverage**

***Transition risk sources*:**

- Policy: Smooth; Shocks on bespoke basis; Using amongst others IEA scenarios; Adaptable to users' beliefs and expectations outside the automated tool;
- Market upstream: Smooth, shock; Industry specific risks in the supply chain, weighted differently depending on the sector in the ISS ESG carbon risk rating; Adaptable to users' beliefs and expectations outside the automated tool;

- Market downstream: Smooth, shock; Industry specific risks and opportunities from a company's products and services, weighted differently depending on the sector in the ISS ESG carbon risk rating; Adaptable to users' beliefs and expectations outside the automated tool;
- Technology: Smooth, shock; Industry specific technology risks, weighted differently depending on the sector in the ISS ESG carbon risk rating. Further, a deep dive into "Energy and Extractives" companies is provided that compares technology requirements in 2030 and 2050 for a 2°C scenario versus actual technology mix; Adaptable to users' beliefs and expectations outside the automated tool.
- Other: -

***Sectors*:** All.

***Countries*:** All.

***Emissions*:**

- $CO_2$ (scope 1-3);
- $CH_4$, $N_2O$, $O_3$, CFCs, HCFCs, HFCs translated into $CO_2e$ for consistent benchmarking across industries.

***Analysis horizon and time steps*:** Scenario analysis extends to 2050 for alignment analysis as well as physical risk assessment.

![ISS ESG ethix·climate·oekom]

## Global portfolio

Climate Impact Assessment

**OVERVIEW**

DATE OF HOLDINGS
30 SEP 2019

COVERAGE
99.99%

AMOUNT INVESTED
9,999,245 USD

BENCHMARK USED
Global Benchmark

PORTFOLIO TYPE
MIXED

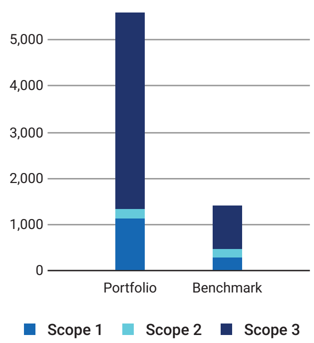
### Carbon Metrics 1 of 3

**Portfolio Overview**

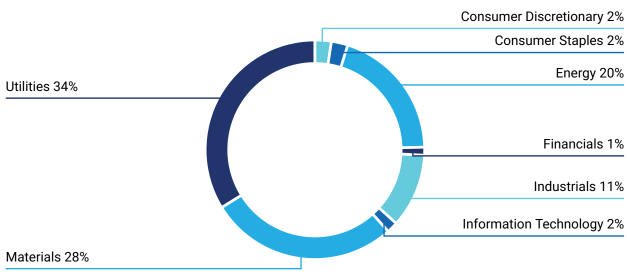
| | Disclosure Number/Weight | Emission Exposure $tCO_2e$ | | | Relative Emission Exposure $tCO_2e$/Mio USD Revenue | | Climate Performance Weighted Avg |
|---|---|---|---|---|---|---|---|
| | Share of Disclosing Holdings | Scope 1 & 2 | Incl. Scope 3 | Relative Carbon Footprint | Carbon Intensity | Weighted Avg Carbon Intensity | Carbon Risk Rating[1] |
| **Portfolio** | 58.6% / 80.5% | 1,339 | 5,587 | 134 | 227 | 215 | 33 |
| **Benchmark** | 92.7% / 98.5% | 443 | 1,381 | 44 | 83 | 113 | 46 |
| **Net Performance** | -34.1 p.p. / -18 p.p. | -201.9% | -304.4% | -201.9% | -172.6% | -89.2% | – |

**Emission Exposure Analysis**

Emissions Exposure ($tCO_2e$)




Sector Contributions to Emissions[2]




[1] Note: Carbon Risk Rating data is current as of the date of report generation.
[2] Emissions contributions for all other portfolio sectors is less than 1% for each sector.

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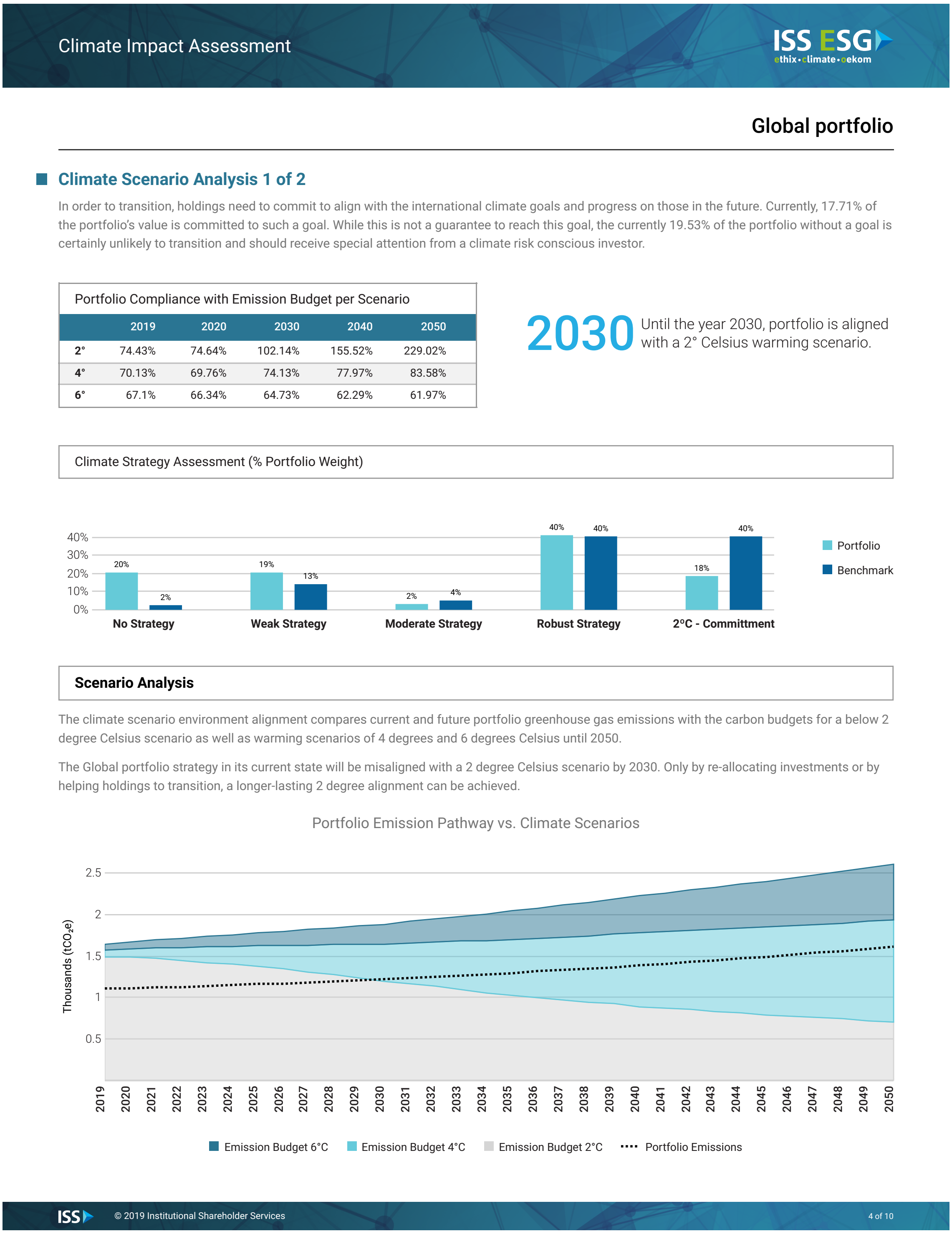
Figure 16: Model overview ISS ESG - Portfolio Climate Impact Report and Raw Data, *Source*: ISS (2019).



Climate Impact Assessment

ISS ESG ethix • climate • oekom

## Global portfolio

### Climate Scenario Analysis 1 of 2

In order to transition, holdings need to commit to align with the international climate goals and progress on those in the future. Currently, 17.71% of the portfolio's value is committed to such a goal. While this is not a guarantee to reach this goal, the currently 19.53% of the portfolio without a goal is certainly unlikely to transition and should receive special attention from a climate risk conscious investor.

Portfolio Compliance with Emission Budget per Scenario

| | 2019 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| 2° | 74.43% | 74.64% | 102.14% | 155.52% | 229.02% |
| 4° | 70.13% | 69.76% | 74.13% | 77.97% | 83.58% |
| 6° | 67.1% | 66.34% | 64.73% | 62.29% | 61.97% |

**2030** Until the year 2030, portfolio is aligned with a 2° Celsius warming scenario.

Climate Strategy Assessment (% Portfolio Weight)



**Scenario Analysis**

The climate scenario environment alignment compares current and future portfolio greenhouse gas emissions with the carbon budgets for a below 2 degree Celsius scenario as well as warming scenarios of 4 degrees and 6 degrees Celsius until 2050.

The Global portfolio strategy in its current state will be misaligned with a 2 degree Celsius scenario by 2030. Only by re-allocating investments or by helping holdings to transition, a longer-lasting 2 degree alignment can be achieved.



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Figure 17: Model overview ISS ESG - Portfolio Climate Impact Report and Raw Data (continued), *Source*: ISS (2019).

| Criteria-based tool analysis | | ISSE |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Full transparency on the models for the tool users |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Self-reported (reported emissions data is gathered from validated sources including sustainability reports, company websites and press releases, and CDP reports); Evaluation of trustworthiness and own calculations (ISS ESG uses its proprietary approximation system to model emissions for non-reporting companies, or those who report with low reliability, according to internal analysis) |
| b) Third party verified | (x) | Own evaluation of trustworthiness and whether reported data is third party verified |
| c) Missing data strategy explained | x | For all non-reporting companies: own emissions modeling methodology (method developed with ETH Zurich, includes over 800 sector and sub-sector models to calculate GHG emissions of companies based on criteria most relevant to their business |
| **3. Science-based approach** | | |
| a) Scientific references | (x) | Tool (partly) developed as part of an academic thesis at ETH. |
| b) Peer reviewed | (x) | The tool was (partly) developed as part of an academic thesis at ETH. Example of review of results by academic institution: see above in "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | IEA SDS sceneario available not yet via report but imminent on the online data platform Datadesk |
| b) Country-differentiated | (c) | In the automatic report: Carbon Risk Rating takes carbon price by geography into account, but no geography differentiation by default. Outside the report: carbon pricing analysis and country-based carbon risk rating available on bespoke basis |
| c) Sector-differentiated | x | The Carbon Risk Rating differentiates per default setting between different sectors |
| **5. Exposure** | | |
| a) Current GHG emissions | x | GHG in $CO_2$e, scope 1-3 for all companies |
| b) Expected GHG emissions | (c) | Can be included on a bespoke basis. Not entire data unit focused on financial valuation of companies (ISS EVA) with detailed historic and forward-looking financial data points available per company, including gross fixed assets and specifically lock-in of maintenance CAPEX (based on 20 years of history) |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (c) | Can be included on a bespoke basis. Dataset mentioned above in 5a) tool setting also includes profit levels, specifically earning levels above a fair level of return when considering capital and operating costs. |
| b) Peers performance, competition | x | Transition-induced change of within-sector competition |
| c) Cost pass-through | (c) | Can be included on a bespoke basis. Dataset mentioned above in 5a) tool setting. On a bespoke basis this can include an analysis to companies price elasticity (e.g. in case of changes to or introductions of carbon prices). |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | |
| **8. Economic impact** | | |
| a) Economic losses and gains | (x) | Potential economic losses in the Carbon Risk Rating (for company and sector). Other calculations available outside automatic report; Gains: View on potential economic opportunities built into the Carbon Risk Rating (for individual company including its specific products/ services and for entire sector). Other calculations available outside the automatic report |
| b) Macroeconomic development | x | Transition-induced change of economy's sectoral composition |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | (c) | On a bespoke basis, modeling of non-linear effects such as litigation possible. |
| b) Financial market amplification | (c) | Outside the tool possible |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | (x) | IEA ETP scenarios: 2DS, 4DS, 6DS; via online platform IEA Sustainable Development, Current Policies and Stated Policies scenario (for tool users) |
| b) Assumptions-based output communication | - | Assumptions reported in separate document: methodology document detailing the tool assumptions both for the scenario alignment methodology as well as emission modeling |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (x) | Start: status quo; Trend: range of IEA scenarios |
| b) Scenario-neutral (various risk realisations) | (x) | IEA scenarios: Energy Technology Perspectives, Sustainable Development Scenario |
| c) Probability distribution input (timing) | (c) | Risk materialization time is explicit, adaptable in the bespoke solution |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | x | separate output |
| b) Trade-off physical-transition risks | dvp | ISS ESG is developing a product that combines physical and transition risk metrics. The scenarios used will be based around those provided by the IPCC in Fifth Assessment Report (AR5) and The Special Report on Global Warming of 1.5 °C (SR15). The risk exposure will be expressed per risk e.g. physical and transition risk, and in a combined score. In addition, risk exposure will be expressed in potential financial impact on the analysed issuer or portfolio. |
| **Climate targets** | | |
| a) Alignment assessed | x | Climate alignment is part of the standard output. Clear indication given as to whether or not a portfolio aligns with the climate targets. |
| b) Financial institution impact analysis | (c) | Possible to measure the climate impact, e.g. in absolute terms by using the GHG protocols ownership approach when associating portfolio emissions to the investor |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation



Table 25: Analysis ISS ESG - Portfolio Climate Impact Report and Raw Data

## MSCI/Carbon Delta - Climate VaR

| | |
|---|---|
| **Full name** | Carbon Delta/MSCI Climate Value-at-Risk Tool (Climate VaR) |
| **Short name** | MSCI |
| **Owner** | MSCI/ Carbon Delta AG (Switzerland) |
| **Developer** | Carbon Delta AG (Switzerland) |
| **Access** | Public, paywall, fixed price and customized options |

Table 26: Summary MSCI/Carbon Delta - Climate VaR

Model Documentation: See Hyperlinks CarbonDelta Online Documentation and MSCI Climate Solutions Online Documentation. Detailed documentation not publicly available, only to prospects and clients. The model behind some part the CarbonDelta method, specifically for global tropical cyclones, European winter storms and global drought, is open-source and -access (Aznar Siguan and Bresch, 2019). The model is ready for donwload and use in the GitHub repository `https://wcr.ethz.ch/research/climada.html`.

### Key characteristics (Based on self-description)

Climate Value-at-Risk (CVaR) is designed to provide a forward-looking and return-based valuation assessment to measure climate related risks and opportunities in an investment portfolio. The fully quantitative model offers deep insights into how climate change could affect company valuations.

In order to identify transition risks and opportunities, the policy scenarios used in the tool aggregate future policy costs based on an end of the century time horizon. By overlaying climate policy outlooks and future emission reduction price estimates onto company data, MSCI ESG Research's model provides insights into how current and forthcoming climate policies may affect companies. The technology scenarios identify current green revenues as well as the low carbon patents held by companies, calculate the relative quality score of each patent over time and forecast green revenues and profits of corporations based on their low carbon innovative capacities.

In order to identify physical risks and opportunities the physical scenarios evaluate the impact and financial risk relating to several extreme weather hazards, such as extreme heat and cold, heavy snowfall and precipitation, wind gusts, tropical cyclones and coastal flooding/sea level rise. The data sources and assessment methods have been established with input from the renowned Potsdam Institute for Climate Impact Research (PIK).

Finally, Climate VaR provides insights into the potential climate-stressed market valuation of investment portfolios and downside risks. MSCI ESG Research's financial modeling approach translates climate-related costs into valuation impacts on companies and their publicly tradable securities. In this way, the Climate VaR framework is designed to help investors to understand the potential climate-related downside risk and/or upside opportunity in their investment portfolios.

### Model setup

***Output metrics*:** Value-at-Risk on asset price, issuer level costs and other intermediate metrics (like reduction requirements, days of extreme weather impact, etc.)

***Output format*:**

- Report in PDF format with output metrics figures and verbal analysis;
- Excel file output metrics, csv, xml and other formats

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions; Emission intensity, using the following metric: emissions / revenue;
- Peer comparison, namely: industry peers.

**Coverage**

***Transition risk sources*:**

- Policy: Smooth ($CO_2$ Price)
- Market upstream: -
- Market downstream: -
- Technology: Smooth (innovative capacity, based on patent data)
- Other: Extreme weather smooth, shock

***Sectors*:** All.

***Countries*:** World.

***Emissions*:** $CO_2$ (scope 1-3).

***Analysis horizon and time steps*:** 1-year and 5-year time steps.

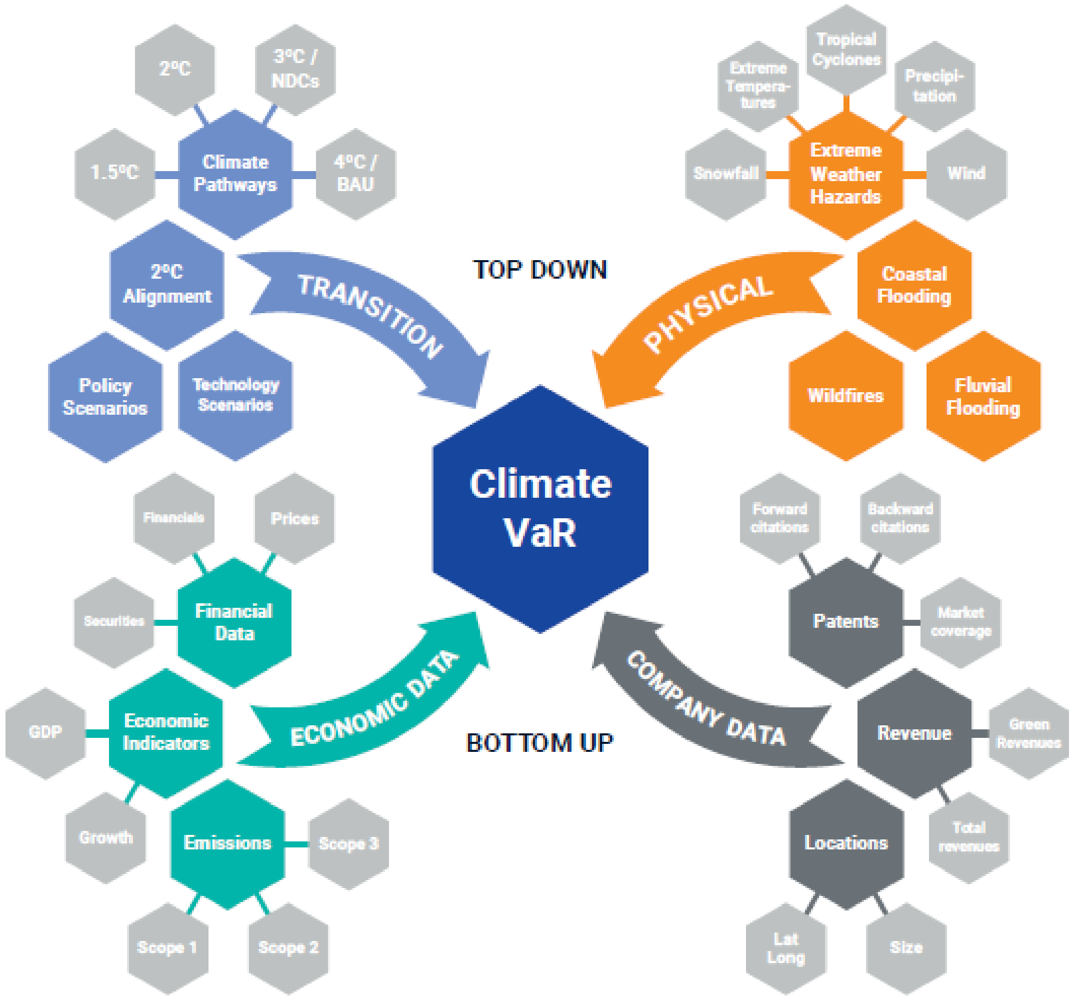


Figure 18: Model overview MSCI/Carbon Delta - Climate VaR, *Source*: MSCI / Carbon Delta (2020).

| **Criteria-based tool analysis** | | MSCI |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Private, tool owner only |
| b) Study questionnaire completed | (x) | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Own estimates: Methodology based on asset locations and intensities of sectors and countries; Self-reported CDP data |
| b) Third party verified | (x) | Own calculations, consistency checks with global, country and sector sums |
| c) Missing data strategy explained | x | Own estimation |
| **3. Science-based approach** | | |
| a) Scientific references | x | See above "Model Documentation" |
| b) Peer-reviewed | (x) | See above "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Various SSPs scenarios/ REMIND model (PIK) |
| b) Country-differentiated | x | Country NDCs and national climate policies taken into account |
| c) Sector-differentiated | x | 51 emissions related sectors and 30 extreme weather related sectors |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | |
| b) Expected GHG emissions | - | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | Profit change calculated, but does not explicitly enter into a vulnerability and adaptability analysis |
| b) Peers performance, competition | (x) | |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | - | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Green R&D, Patents |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, loss in revenues; Gains: Increase in profits, increase in revenues, patent values |
| b) Macroeconomic development | x | |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | - | |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | (x) | Tool users only; Scenarios: REMIND (PIK) |
| b) Assumptions-based output communication | . | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | |
| b) Scenario-neutral (various risk realisations) | x | Various SSPS from REMIND, customizations possible, e.g. Scenario choice, carbon price inputs, percentiles for extreme weather calculations |
| c) Probability distribution input (timing) | (c) | |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | x | Extreme weather |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | x | Separate indicators (portfolio warming potential calculation) |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 27: Analysis MSCI/Carbon Delta - Climate VaR

## Oliver Wyman - Climate Transition Risk Methodology

| | |
|---|---|
| **Full name** | Oliver Wyman climate transition risk methodology |
| **Short name** | OLWY |
| **Owner** | Oliver Wyman |
| **Developer** | *same as owner* |
| **Access** | Customized consulting services |

Table 28: Summary Oliver Wyman - Climate Transition Risk Methodology

Model Documentation: UNEP FI (2018).

### Key characteristics (Based on self-description)

The key aim of the methodology is to help banks assess the transition-related exposures in their corporate loan portfolios where they may have concerns about the potential policy and technology related impacts of a low-carbon transition, as well as an appetite to explore and capture the associated opportunities. The methodology identifies how a low-carbon policy and technology transition to mitigate climate change could impact the credit risk of a bank's corporate loan portfolio, as well as its commercial strategy (UNEP FI, 2018).

This framework allows to compute, through climate scenarios, direct and indirect emission costs, low-carbon CAPEX, change in revenues and segment sensitivities to risk factors. This output is joint with a borrower-level credit rating calibration in order to provide a portfolio impact assessment via borrower characteristics (standard) and climate credit quality index (by segment and geography). The output is the impact on expected losses. More specifically, the impact of climate scenarios on the various corporate performance drivers (price, volume, capital expenditure, costs) is modeled. Then, this impact is translated into scenario-adjusted profit and loss, balance sheet, and cash flow statements at a borrower-level before converting them to credit risk impact.

### Model setup

***Output metrics*:** Scenario-adjusted

- Probability of default;
- Rating;
- Expected loss.

***Output format*:** Excel file with charts.

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions; Emission intensity;
- Production capacity;
- Transition readiness.

Coverage

***Transition risk sources*:**

- Policy: Smooth, shock;
- Market upstream: Smooth, shock;
- Market downstream: Smooth, shock;
- Technology: Smooth, shock;
- Other: -

***Sectors*:** All.

***Countries*:** World.

***Emissions*:** Sector-dependent.

***Analysis horizon and time steps*:** Annual time steps, today until 2060.

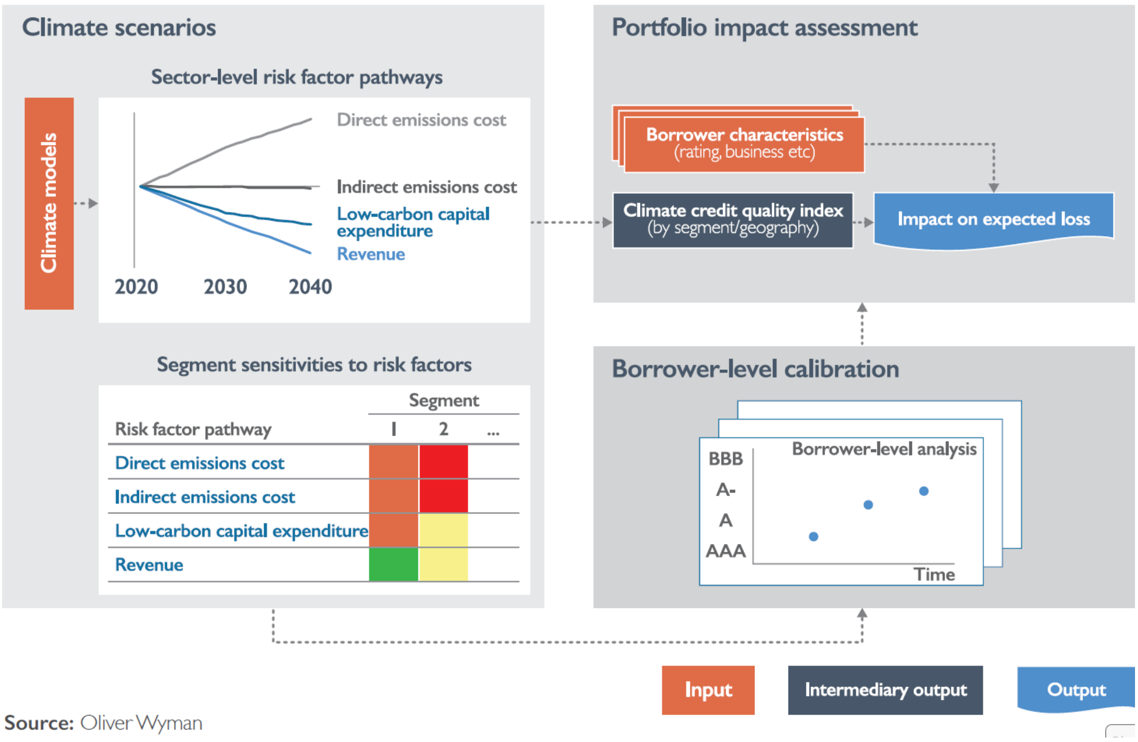


Figure 19: Model overview Oliver Wyman - Climate Transition Risk Methodology, *Source*: UNEP FI (2018).

| **Criteria-based tool analysis** | | OLWY |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Code is private, tool owner only; Detailed approach and modules description available online (see above "Model Documentation") |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Third party provider IAMC, and other: Use of proxy (e.g. number of barrels produced) |
| b) Third party verified | (x) | External provider (see element 2a)) |
| c) Missing data strategy explained | x | Use of proxy (e.g. number of barrels produced) and industry averages |
| **3. Science-based approach** | | |
| a) Scientific references | (x) | Collaboration with PIK and IIASA |
| b) Peer-reviewed | - | |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | |
| b) Country-differentiated | x | Tailored to exposures, user-specific |
| c) Sector-differentiated | x | Tailored to specific companies being analyzed, user-specific |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Sector-dependent, all scopes covered |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | x | |
| b) Peers performance, competition | x | Transition-induced change of within-sector competition |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, loss in revenues (decrease in demand, increase in wholesale prices); increase in production costs (increase in input prices, increase in production-related fix and variable costs); other (impairment / stranded assets); sector-dependent; Gains: Increase in profits, increase in revenues (increase in demand, wholesale prices lower than competitors), decrease in production costs; sector-dependent |
| b) Macroeconomic development | x | Transition-induced change in economy's sectoral composition and trade patterns; sector-dependent |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | x | |
| b) Financial market amplification | x | Network effects, balance sheet effects |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | (x) | Scenarios: REMIND (PIK), MESSAGEix-GLOBIOM (IIASA) |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (x) | IAMC models |
| b) Scenario-neutral (various risk realisations) | (x) | IAMC or in-house models, provider: PIK/IIASA/OliverWyman |
| c) Probability distribution input (timing) | (c) | |
| d) Probability distribution output (values) | (x) | Stochastic version allows to derive the entire probability distribution through visual representations as well as quantified outputs (median, mean. percentiles, VaR,...) |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | dvp | Related approach is being developed for physical risk |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | - | |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 29: Analysis Oliver Wyman - Climate Transition Risk Methodology

## Ortec Finance - ClimateMAPS

| | |
|---|---|
| **Full name** | ClimateMAPS - systemic climate risk aware economic and financial scenario sets |
| **Short name** | ORTE |
| **Owner** | Ortec Finance |
| **Developer** | Ortec Finance, in partnership with Cambridge Econometrics |
| **Access** | Private tool, access requires either dataset subscription or one-off report delivery contract. |

Table 30: Summary Ortec Finance - ClimateMAPS

Model Documentation: Methodology document available only to clients, various joint publications containing methodology overview, e.g. Bongiorno et al. (2020b) and Bongiorno et al. (2020a)

### Key characteristics (Based on self-description)

The Ortec Finance climate-savvy scenarios sets and balance sheet simulation software integrates quantified risks and opportunities associated with climate change into traditional forward-looking financial scenarios sets that drive strategic investment decision-making. This climate-adjusted economic and financial outlook allows investors to analyze the impacts of various global warming pathways on their balance sheet simulation (Eichler and Verdegaal, 2019).

### Model setup

***Output metrics*:**

- Quantified climate risk-aware economic and financial outlooks up to 2100, differentiated by country for a selection of 600+ economic and financial variables;
- Macroeconomic impacts (GDP growth rates, interest rates, inflation);
- Impacts on asset classes performance in % (equity, bond, credits, real estate, etc.);
- Fund total impacts (on risk/return in %, funded ratio in %, and in terms of asset values in own currency);
- Various more detailed metrics such as risk of bankruptcy, underfunding, cut in nominal pension benefits, etc.

***Output format*:** Flexible. Various delivery options:

- Climate risk aware financial and economic dataset file delivery license for clients to use in their own economic scenario generators, SAA/ALM tooling;
- Service contract where Ortec Finance analyzes client's portfolio and delivers results in a report format.

***Risk indicator*:**

- Climate-adjusted financial risk indicator: Methodology to capture transition risk exposure is based on Cambridge Econometric's E3ME model. Transition risk exposure is measured by looking how policy and technology drivers impact broader macro-economic interactions worldwide (e.g. supply demand relationships, supply chain dependencies, etc.) per sector and country and how this changing macro-economic outlook in turn impacts the portfolio's risk exposure across asset classes, sectors and countries.

**Coverage**

***Transition risk sources*:** Standard offering always includes three climate scenarios: Paris Orderly Transition, Paris Disorderly Transition, Failed Transition.

- Policy: Smooth, shock; An alternative disruptive policy scenario is a delayed policy response and consequent steeper policy/technology requirements in the years 2025-2035 to still limit average global temperatures in line with the Paris Agreement; Adaptable to users' beliefs and expectations;
- Market upstream: Smooth, shock; Adaptable to users' beliefs and expectations;
- Market downstream: Smooth, shock; Adaptable to users' beliefs and expectations;
- Technology: Smooth, shock; Adaptable to users' beliefs and expectations;
- Other: Smooth, shock; Financial markets: for the transition scenarios considered (1.5/ 2°C), two alternatives exists (a) an orderly transition and (b) a disorderly transition. The disorderly transition represents a disruptive financial shock (e.g. carbon bubble bursting/stranded asset impacts) in the shorter term. Market pricing in assumptions also differ between these two alternative scenarios; Adaptable to users' beliefs and expectations.

***Sectors*:** Climate-related impacts on sectors are differentiated based on the GICS classification (currently up to level 1, up to level 4 under development).

***Countries*:** Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Hong Kong, India, Italy, Malaysia, New Zealand, Norway, Russia, Singapore, South Korea, Spain, Sweden, Switzerland, Taiwan, The Netherlands, United Kingdom, USA.

***Emissions*:** $CO_2$, sector-dependent; User-specific (cf. E3ME Model documentation).

***Analysis horizon and time steps*:** Deliver results in annual time steps up to 2100. Impacts can be differentiated between short- (now-2030), medium- (2030-2050), and long-term (2050+) horizons. Usually 40 years proposed to capture most pension funds/insurance companies' time horizon interest, and because the degree of certainty associated with the estimates is stronger in the nearer term; User-specific (Eichler and Verdegaal, 2019).

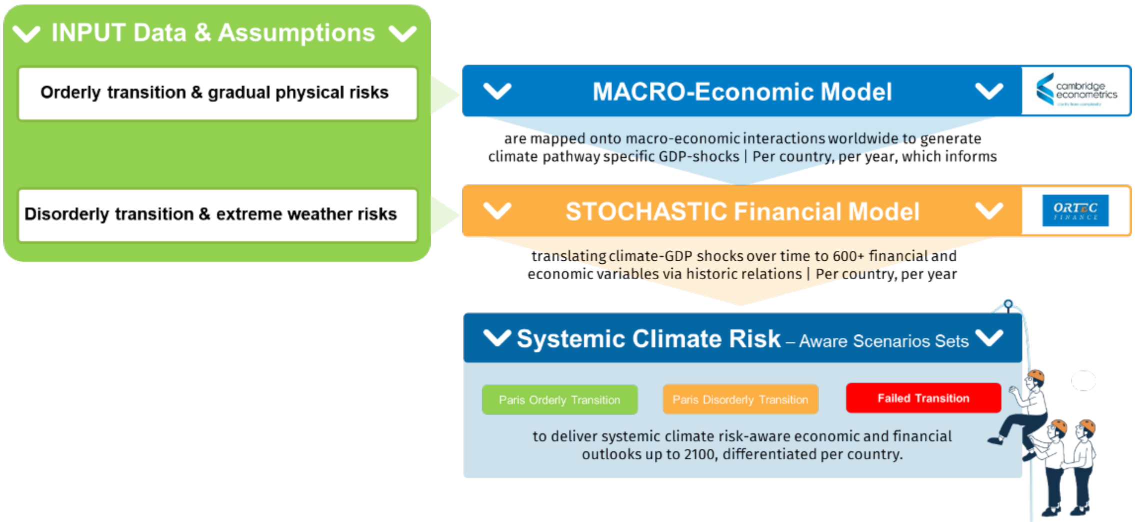


Figure 20: Model overview Ortec Finance - ClimateMAPS. *Source*: Eichler and Verdegaal (2019).

| **Criteria-based tool analysis** | | ORTE |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Available to clients if a yearly subscription is purchased. Two options: a) One-off contract: report and/or the climate impacts in an excel file; b) Subscription: report/climate impacts each semester if desired and access to the software to run own simulations |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | (x) | Estimated by Cambridge Econometrics (use publicly available data sources) |
| b) Third party verified | (x) | Modelling approach not rely on accuracy of emissions data; Top-down approach: total global carbon budget and national level emissions data are most important. Sources typically already cross-verified and more reliable than company level emissions data |
| c) Missing data strategy explained | (x) | See element 2a, 2b |
| **3. Science-based approach** | | |
| a) Scientific references | x | E3ME/Cambridge econometrics scenarios and various academic papers (Burke and Tanutama, 2019) |
| b) Peer-reviewed | (x) | Only the E3ME parts |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | User-specific |
| b) Country-differentiated | x | Differentiated along country coverage (see above "Countries") |
| c) Sector-differentiated | x | Differentiate the various types of climate-related impacts on sectors based on the GICS classification (currently up to level 1, working on up to level 3) |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | $CO_2$ only (other GHG estimated, cf. E3ME model documentation); sector-dependent |
| b) Expected GHG emissions | - | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | - | |
| b) Peers performance, competition | - | |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | - | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in revenues: Bespoke sector and/or country based demand changes, increase in production costs (technology-related costs, available as E3ME output on bespoke basis); Gains: Same mechanism as for losses |
| b) Macroeconomic development | x | Change of within-sector competition, economy's sectoral composition, trade patterns and other(can be adjusted based on user beliefs) |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | x | |
| b) Financial market amplification | x | Network effects, revision of investor expectations / sentiment; Use stochastic financial model to feed in the climate-adjusted macro-economic risk drivers; Capture multitude of interactions which can act as amplification mechanisms |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Tool users only: detailed modeling assumptions (can also be adjusted based on client beliefs for customized climate scenarios on bespoke basis); White papers on underlying models and assumptions available on request |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (x) | 1) Default baseline Ortec Finance Scenarioset (OFS), 2) own baseline assumptions, or 3)"Difference to baseline" (DTB) version with shock deltas only. OFS: world temperature increased of 0.8°C but will not warm any further; Policy/technology progress achieved up to 2020 is priced into markets; Committed current policies will remain. Dataset can also be delivered as DTB: enables the user to map the climate impacts to own reference/baseline scenario |
| b) Scenario-neutral (various risk realisations) | (x) | Set of stochastic and deterministic economic and financial scenarios |
| c) Probability distribution input (timing) | (c) | Several sources of risk materialize at different points in time (transition risk, gradual physical risk, market pricing-in of impacts etc.); Bespoke modeling possible |
| d) Probability distribution output (values) | (x) | Deterministic and stochastic approach of climate aware economic and financial scenarios. In the stochastic offering, probability distribution through visual representations and quantified outputs (median, mean, percentiles, VaR, etc.) |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | x | Losses caused by climate impacts affecting the performance of specific asset classes, sectors, or geographical areas. These losses then affect asset return (and value), liabilities, or both); Differentiate by "gradual physical risks" and "climate-related extreme weather events" |
| b) Trade-off physical-transition risks | x | Transition and physical risk drivers interact with each other across sectors and regions via the macro-econometric model, E3ME. This may lead to amplifications of risk and captures worldwide interdependencies |
| **Climate targets** | | |
| a) Alignment assessed | dvp | Alignment tooling currently being developed, expected market readiness in Q2/2020. The tool will be able to run separately or in combination with the climate risk tool |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 31: Analysis Ortec Finance - ClimateMAPS

## PwC/The CO-Firm - Climate Excellence

| | |
|---|---|
| **Full name** | Climate Excellence |
| **Short name** | PWC |
| **Owner** | PricewaterhouseCoopers GmbH WPG (PwC) |
| **Developer** | First version by The CO-Firm, further development by PwC |
| **Access** | Public, paywall, customized |

Table 32: Summary PwC/The CO-Firm - Climate Excellence

Model Documentation: See Hyperlink PwC Online Documentation. A detailed list of publications can be found below in the analysis table under 3a) Scientific references.

### Key characteristics (Based on self-description)

The methodology behind Climate Excellence provides a forward-looking financial assessment of climate related risks and opportunities with the general flexibility to build upon any scientific scenario and cover any level of detail for assets with real economy underlying. The key features of the tool are:

- The tool builds on fundamental analysis, enabling the assessment of risks also from market and competitive dynamics, technological advancements, and regulations that also extend beyond carbon prices (quotas, energy efficiency requirements, energy subsidies). Thereby, it allows for contrasting the existing risk framework, as well as the sector and macroeconomic outlooks with what could happen under the different climate scenarios, as the basis for a consistent and easy integration into existing financial institution methodologies and frameworks;
- A bottom-up asset-level modeling, allowing integrated insights on a plant, technology, company, country and sector level;
- Geographic granularity corresponding to specific sector characteristics;
- View on the specific risk position of the real economy counterparty, as the tool provides insights on the impact of strategic choices of companies (adaptive capacity).

The Climate Excellence online tool for investment is available under: `https://store.pwc.de/en/climate-excellence`. A solution for banking is under development and follows shortly after publication of this study. For further releases, please refer to Hyperlink: PwC Online Documentation.

### Model setup

***Output metrics*:** Change in

- EBITDA;
- Earnings before interest taxes (EBIT);
- CAPEX Sales;

- Volume and other financial KPIs as applicable.

***Output format*:** Tool and consulting. For Consulting, results representation available in any format (xls, ppt, pdf, etc.). For the online tool (license based) results are visualized online with reporting option as xls and pdf.

***Risk indicators*:**

- Economic climate risk indicator: Emission intensity, using the following metric: implicitly as one of many sector-specific indicators of plant/company financial competitiveness;
- Production capacity;
- Peer comparison (global/regional market model);
- Transition readiness (technology share of production portfolio, sector specific);
- Sector specific indicators: Climate relevancy (significant price, demand etc. changes expected) paired with financial relevancy of industry branch;
- Other: Market impact of scenarios (demand, price), sector specific market allocation logic.

**Coverage**

***Transition risk sources*:**

- Policy: Smooth, (shock in development); Removal of fossil fuel subsidies, carbon pricing regulation, energy efficiency/life-cycle GHG (transportation, real estate etc.), strengthening of renewable energy sources, development of gas-fired technology & increasing CCS, phase out of coal, taxation of transportation etc.
- Market upstream: Smooth, (shock in development); Availability of raw materials, cost (dis-) advantages between regions, relative input prices, relative supply cost;
- Market downstream: Smooth, (shock in development); Changed demand due to GDP and population growth/decline, sector coupling, reputation etc., relative price changes, recycling etc.;
- Technology: Smooth, (shock in development); Cost curve, new technologies, relative competitiveness;
- Other: -

***Sectors*:** All.

***Countries*:** Provide global and country coverage, aggregated in a portfolio view to seven world regions (Asia Pacific, Africa, Eurasia, Europe, Latin America, Middle East, North America).

***Emissions*:** Sector-dependent.

***Analysis horizon and time steps*:** 2025, 2030, 2040, 2050.

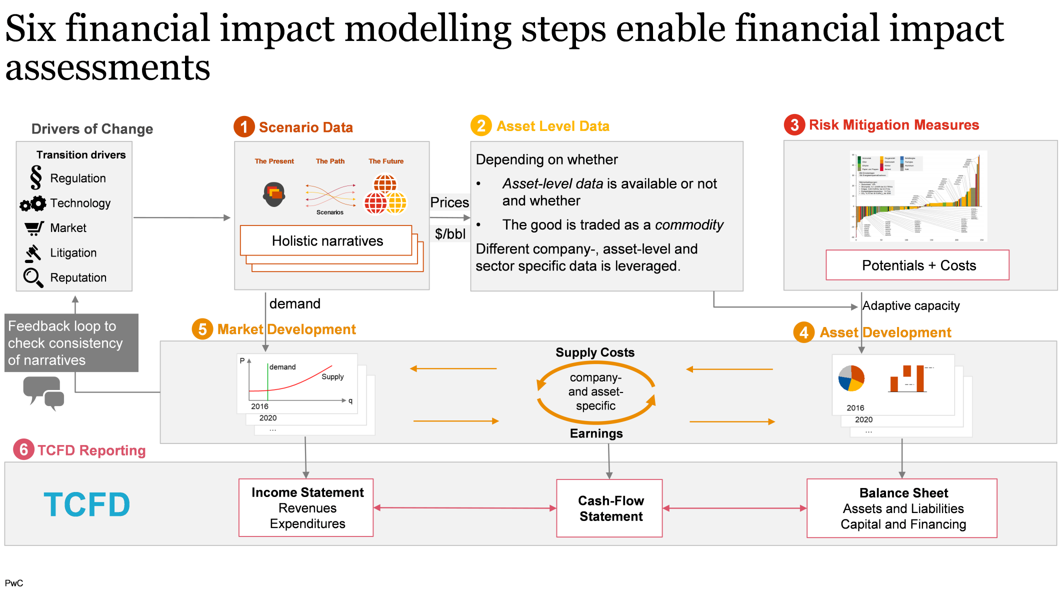


Figure 21: Model overview PwC/The CO-Firm - Climate Excellence. *Source*: See Hyperlink PwC Online Documentation.

| **Criteria-based tool analysis** | | PWC |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Private, tool owner only |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Own databases on plant structures, technology optimisation options, asset/technology costs, efficiency gains and energy costs. Emissions: self-reported data with validation/cross-checking. Third-party databases (e.g. Asset resolution) are included where they can improve analysis |
| b) Third party verified | (x) | see element 2a) |
| c) Missing data strategy explained | (x) | Not critical, $CO_2$ is often a minor risk driver (most financial effects are linked to changes in input prices and competitive dynamics) |
| **3. Science-based approach** | | |
| a) Scientific references | x | See references on next page |
| b) Peer-reviewed | x | See references on next page |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | |
| b) Country-differentiated | (x) | Provide global and country coverage, aggregated in portfolio view of seven world regions (Asia Pacific, Africa, Eurasia, Europe, Latin America, Middle East, North America) |
| c) Sector-differentiated | x | Differentiation by NAICS industry branches and includes mapping to sectors defined by the TCFD |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | Sector-dependent (during the tool development the focus sectors are considered, based on financial materiality and emission intensity). However, GHGs are not the biggest driver in the analysis (key drivers are input prices and competitive dynamics). |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | x | Financial propensity |
| b) Peers performance, competition | x | Current competitive position and structural advantages |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, loss in revenues (decrease in demand, increase in wholesale prices); Increase in production costs (increase in input prices, fix costs, variable costs); Other: Changes in resource and input prices; Changes in demand for products / services; Supply chain disruptions; Changes in CAPEX; Gains: Changes in resource and input prices; Changes in demand for products /services; Investment into profitable business cases (e.g. efficiency gains) |
| b) Macroeconomic development | x | Change in population, GDP, economy's sectoral composition |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | - | |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Full transparency on scenarios, scenario narratives, scenario assumptions and model assumptions for clients |
| b) Assumptions-based output communication | (x) | Assumptions and FAQs are provided alongside the output |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (x) | Range of default baseline scenarios, sector-dependent (see ET Risk for example) |
| b) Scenario-neutral (various risk realisations) | (x) | Range of IEA scenarios to choose from: Below 2°C, 2°C, Reference Technology Scenario |
| c) Probability distribution input (timing) | - | There is no flexibility as developments are fixed within the boundaries of the scenario |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | dvp | Financial impact assessment of all hazards types, both chronic and acute, geography-specific and for all sectors depending on financial materiality |
| b) Trade-off physical-transition risks | - | No trade-off between physical and transition but rather an additive financial impact |
| **Climate targets** | | |
| a) Alignment assessed | (c), dvp | Climate target alignment is part of the overall methodology and is possible consultancy based. For the online tool an alignment assessment is under development. |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 33: Analysis PwC/The CO-Firm - Climate Excellence

**Tool setup information on criterion 3: Science-based approach**

- The approach of Climate Excellence has been co-developed with leading financial institutions, inputs/ modeling been academically validated and tested with companies over several years: Cambridge Institute for Sustainability Leadership, and The Energy Transition Risks & Opportunities (ET Risk) research consortium seeks to provide research and tools to assess the financial risks and opportunities associated with the transition to a low-carbon economy (see `http://et-risk.eu/`).
- Röttmer, N. (2018) "Szenarioanalysen und TCFD - ein Beitrag zum Risikomanagement und zur Finanzierungs- bzw. Investitionsstrategie?" In Stapelfeld, M., Granzow, M. and Kopp, M.. Greening Finance. Der Weg in eine nachhaltige Finanzwirtschaft, p. 269 - 282;
- University of Cambridge Institute for Sustainability Leadership (2016) "Feeling the heat: An investors' guide to measuring business risk from carbon and energy regulation" (See Hyperlink: CISL 2016 Online Report);
- TCFD Think Tank (2019) "User Guidance on TCFD Recommendations. Implementing TCFD step by step in your company" (See Hyperlink: TCFD Think Tank 2019 Report);
- G20 Green Finance Study Group (2017) "G20 green finance synthesis report" (See Hyperlink G20 GFSG 2017 Report;
- Scenario data in usage is developed by the IEA using scientific criteria (See Hyperlink Energy Technology Perspectives Online Documentation);
- Asset level data - as a basis of our tool - validated by Oxford University (See Hyperlink Oxford University Online Resource);
- Operationalization of scenarios: 2°C Investing Initiative, The CO-Firm (2017), "The Transition Risk-o-Meter; Reference scenarios for financial analysis";
- Key documents for risk mitigation measures: Fleiter et al. (2013), Brunke (2017);
- Understanding key sectoral dynamics: IEA Special Reports focusing on different sectors in detail and sector reports of analysts.

## right. based on science - XDC Model

| | |
|---|---|
| **Full name** | X-Degree Compatibility Model (XDC Model) |
| **Short name** | RIGH |
| **Owner** | right. based on science |
| **Developer** | *same as owner* |
| **Access** | baseline XDC: public, fee access; target XDC and sector XDC: public customized paywall |

Table 34: Summary right. based on science - XDC Model

Model Documentation: See Hyperlink right. based on science Online Documentation and Helmke et al. (2020)

### Key characteristics (Based on self-description)

The calculation undertaken by this tool is based on how many emissions an economic entity needs in order to generate 1 million Euros of Gross Value Added (GVA) between a base year and 2050.

The model assesses the climate impact of an economic entity such as a company, a portfolio or a country. The climate impact is expressed directly in degrees Celsius. It corresponds to the amount of global warming until 2050 that would take place under the assumption of every economic entity operating as emission intensively as the one under evaluation under a chosen scenario. The metric is called the X-Degree Compatibility (XDC) and it is computed by an economic climate impact model called XDC Model. The parameters of the XDC Model can be adjusted by the user, which means that XDC values with different purposes can be computed for contextualizing single XDC values and conducting a proper scenario analysis. The most important parameters are:

- Baseline XDC values: describing the climate impact under a baseline scenario assuming a continuation of past trends;
- Scenario-based XDC: describing the climate impact under a relevant scenario;
- Sector XDC values: comparing e.g. a company's baseline XDC to its sector;
- Target XDC values: translating <2°C scenarios into target benchmarks for the economic entity.

The logic behind the model consists of three major steps (See Hyperlink WhatIf Online Report, 2019):

1. Economic Emission Intensity (EEI) definition.
    - For companies: EEI is the amount of GHG emissions per million Euro GVA. In order to calculate the company's EEI, its emissions corresponding to the period between the base year up to 2050 are linked to the GVA corresponding to the same period. Since both direct and indirect emissions are included in the calculation of the EEI, double counting might occur. In order to avoid that, indirect emissions are only partially counted by the XDC analysis (the XDC covers all emisisons and counts only 50% of indirect emission);

- For countries: EEI is calculated as country-level emissions per capita;

2. The company-specific EEI is scaled up to compute global emissions.

   - For companies: using the values for global GVA for the period between the base year up to 2050, the amount of emissions that would reach the atmosphere by 2050 if all companies operated as emission intensively as the one at hand under the chosen scenario, is computed;
   - For countries: using the respective global per capita figures for countries, the amount of emissions that would reach the atmosphere by 2050, if all countries had as much emissions per capita as the one at hand under the chosen scenario, is computed;

3. Accredited findings on climate science are used to calculate the amount of global warming that would occur, if the amount of emissions calculated in step two were to be released into the atmosphere. In order to determine the impact of emissions on the climate the climate model Finite Amplitude Impulse-Response (FaIR) is used. This model includes a comprehensive carbon cycle, it is used by the IPCC and referenced in several scientific publications.

**Model setup**

***Output metrics*:** The main output is issued by means of a Metric, the XDC. There is a difference between a Baseline XDC, Scenario XDC, Sector XDC and Target XDC. They are all possible outputs of the Model but have a different purpose (see description above);

***Output format*:** The output format for the user of the tool depends on the required depth of the analysis and is either:

- A PDF report;
- An Excel sheet;
- An interactive web-based application with XDC values corresponding to each analysed entity.

For detailed and advanced analyses, a software is provided that gives the opportunity to export relevant outcomes as either CSV or PDF.

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions; Emission intensity, using the following metric: $CO_2e$/GVA and $CO_2e$/capita (countries);
- Peer comparison, namely: XDCs can be computed for individual relevant peer groups. Companies within the same sector are e.g compared with each other by contrasting their XDCs to the Sector XDC;
- Other: Target XDCs, established <2°C-scenarios are translated into sector-specific Target XDCs, Scenario-based XDCs for understanding whether the climate impact of a company is a material risk.

,

**Coverage**

***Transition risk sources*:**

- Policy: Smooth (default), shock (if scenario available); Scenario-neutral, fully flexible to incorporate smooth and disorderly developments. Default: carbon price in the five different SSPs;
- Market upstream: Smooth (if scenario available), shock (if scenario available);
- Market downstream: Reputation; Further smooth (if scenario available), shock (if scenario available);
- Technology: Smooth (if scenario available), shock (if scenario available);
- Other: Smooth (if scenario available), shock (if scenario available).

***Sectors*:** All.

***Countries*:** World, with a connection to a Macroeconomic Model; single country resolution planned for 2021.

***Emissions*:** Sector-dependent: $CO_2$, $CH_4$, $N_2O$, $O_3$, $CO_2$ (all scope 1-3).

***Analysis horizon and time steps*:** fully flexible - results are displayed for 2050 (2100 in 2020) and cover assumptions for GVA and emission data that can be adjusted yearly / flexibly.

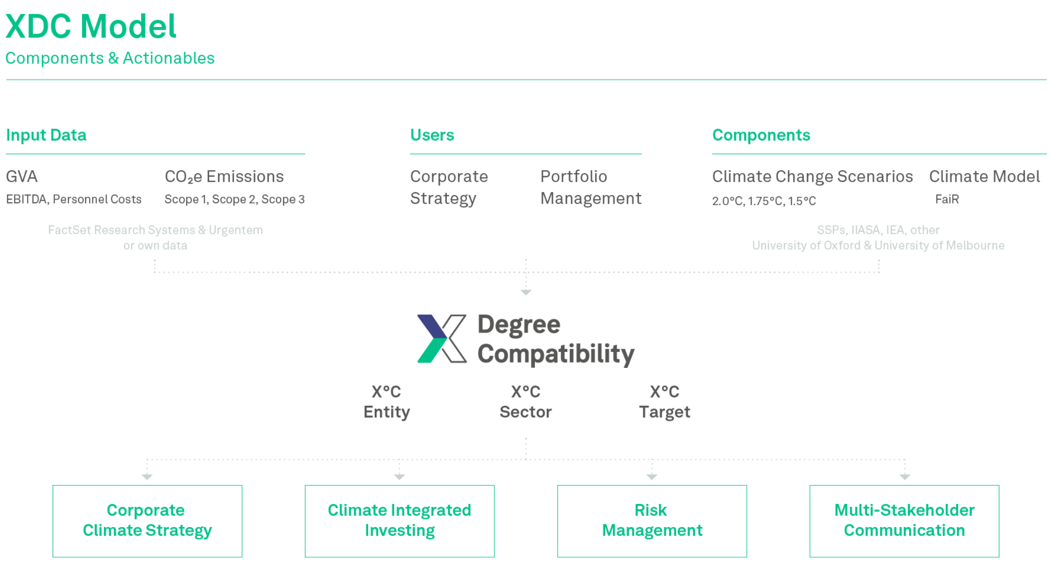


Figure 22: Model overview right. based on science - XDC Model, *Source*: WhatIf (2019).

| **Criteria-based tool analysis** | | RIGH |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | (x) | Online handbook publicly available; the base code of the XDC Model is freely and accessible for researchers through right.open already and will be open source in 2021. Accessible via GitLab |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Data sources provided in the academic article. Emission data default: modeled by third data provider (Engaged Tracking) based on CDP data. Tool users can use any emission data to compute XDC values. The tool can be connected to own databases |
| b) Third party verified | x | Third party provider of emission data with sound verification strategy |
| c) Missing data strategy explained | (x) | See element 2a) and 2b) |
| **3. Science-based approach** | | |
| a) Scientific references | x | Use MESSAGE-GLOBIUM SSPs besides IEA scenarios; Publication locates tool in scientific literature |
| b) Peer-reviewed | x | Peer-reviewed article published in the Handbook of Climate Services (Springer), link in Model Documentation |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Not limited to a °C number, since tool measures climate impact from bottom up; All scenarios leading to certain temperature limit can be used to retrieve Target XDCs |
| b) Country-differentiated | x | Currently: in manual analysis; Future: via macroeconomic model |
| c) Sector-differentiated | x | Currently: in manual analysis; Future: via macroeconomic model |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Sector-dependent materiality analysis |
| b) Expected GHG emissions | x | Covered by scenario-based XDCs; User-specific |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | Calculate via change in revenues and costs, but no influence on core model risk metric; User-specific |
| b) Peers performance, competition | - | Can compare model outputs for various companies but no impact on model output; User-specific |
| c) Cost pass-through | x | Covered by scenario-based XDCs; User-specific |
| **7. Adaptability** | | |
| a) Input substitution | x | Covered by scenario-based XDCs; User-specific |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Covered by scenario-based XDCs; User-specific |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in revenues, increase in wholesale prices, increase in fixed and variable production costs: can be considered in scenario-based XDC; Connection to Macroeconomic Model to cover key drivers for GVA and emissions development. Repercussions of climate impact risks on economic loss of the company can be operationalized (double materiality; Connection between inside-out and outside in perspective); Gains: Same as for losses |
| b) Macroeconomic development | x | Upcoming connection to Macroeconomic model covers macroeconomic non-linearities; User-specific |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | x | Macroeconomic non-linearities (upcoming), scenario-based XDC covers micro-economic non-linearities; User-specific |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Online Handbook publicly available (see element 3b) |
| b) Assumptions-based output communication | (x) | Assumptions tabs provided and a test of users understanding and awareness of the assumption is included |
| **11. Uncertainty** | | |
| a) Baseline adaptable | - | MESSAGE-GLOBIUM SSP 2 Marker scenario (use growth rates for emissions and GVA); In development: connecting a Macroeconomic Model to retrieve consistent set of assumptions for key driving forces |
| b) Scenario-neutral (various risk realisations) | x | Scenario-neutral, default for Target XDCs: sector-specific IEA 2DS or B2DS scenario |
| c) Probability distribution input (timing) | (x) | Can be changed in the Scenario Explorer |
| d) Probability distribution output (values) | (c), dvp | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs. Will apply uncertainty analysis to all material parameters of the model, assess cascading effects and their impact on the outcome (academic project with LUT university applied mathematics, Finland, first results mid/end 2020). |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | - | Physical risk from other tools and their impact on GVA could be considered by the climate impact analysis of the XDC Model |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | x | Climate risk and climate targets alignment are both analysed and provided as separate analysis output |
| b) Financial institution impact analysis | x | Determine the climate impact of financial institutions and financial products, such as portfolios, indexes or gov bonds. |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 35: Analysis right. based on science - XDC Model

## Science-based targets initiative - SBT Tool and SDA Transport Tool

| | |
|---|---|
| **Full name** | Science-based Target Setting Tool (SBT Tool), Sectoral Decarbonization Approach – Transport Tool (SDA Transport Tool) |
| **Short name** | SBTI |
| **Owner** | The Science Based Targets initiative |
| **Developer** | CDP, WRI and WWF with the technical support of Navigant (formerly Ecofys) |
| **Access** | Public, free access |

Table 36: Summary Science-based targets initiative - SBT Tool and SDA Transport Tool

Model Documentation: See Hyperlinks SBTI Online Resources, SBTi (2015), SBTi (2018), SBTi (2019)

### Key characteristics (Based on self-description)

The SBT initiative aims to provide companies with advice on by how much and how quickly they need to reduce their GHG emissions in order to be consistent with climate goals. This methodology can also be applied to unlisted asset classes, such as real estate. The Sectoral Decarbonization Approach (SDA) tool was developed by the SBTi partners with technical support from Ecofys. The SDA tool allocates the energy-related carbon budget to different sectors. The allocation takes into account inherent differences among sectors, such as mitigation potential and how fast each sector can grow relative to economic and population growth. Within each sector, companies can derive their science-based targets depending on their relative contribution to the total sector activity and their carbon intensity relative to the sector's intensity in the base year. Therefore, the rate of reduction varies per company depending on how close their intensity is at present compared to the sector. Using the detailed sector scenarios from the IEA's 2DS and B2DS models, it is possible to estimate the 2DS or B2DS compatible carbon intensity for each sector scenario by dividing the total direct emissions of the sector in any given year by the total activity of the sector in the same year. This yields a sector intensity pathway.

For homogeneous sectors, physical activity indicators - for example, tons of cement, passenger-kilometers (pkm), kilowatt-hours (KWh) – convergence is used as the carbon allocation method. The assumption is that the emissions intensity of each company in the same sector will converge with the sector emissions intensity by 2050. A company's intensity pathway - given by the SDA tool - multiplied by their projected activity yield a company's carbon budget in absolute terms for the target period. In principle, the sum of these budgets should be contained within the sector projected budget given by the IEA in each of the above-mentioned scenarios (SBTi, 2018).

### Model setup

***Output metrics*:**

- % reduction of absolute emissions in selected target year;
- % reduction of carbon intensity in selected target year as per physical carbon intensity denominator corresponding to selected SDA sector ($tCO_2$/MWh gross electricity;

$tCO_2$/Tonnes of crude steel; $tCO_2$/Tonnes of cement; $tCO_2$/Tonnes of aluminium; $tCO_2$/Tonnes of paper and board; $kgCO_2$/Square meters; $gCO_2$/pkm; $gCO_2$/vkm; lge/100km; gCO2/tkm);

- Economic carbon intensity denominator in $tCO_2$/USD of value added (scope 3 only);
- Custom physical intensity denominator in $tCO_2$/custom physical unit as defined by user (scope 3 only).

***Output format*:** Excel file with figures on the output metrics.

***Risk indicators*:**

- Economic climate risk indicator: Absolute emissions in $tCO_2$; Emission intensity (see metrics above).

**Coverage**

***Transition risk sources:*** None as no risk tool, just target:

- Policy: -
- Market upstream: -
- Market downstream: -
- Technology: -
- Other: -

***Sectors*:**

- Power generation;
- Cement;
- Iron and Steel;
- Aluminum;
- Chemicals and Petrochemicals;
- Pulp and paper;
- Other industry;
- Light-duty road passenger transport;
- Heavy-duty road passenger transport;
- Rail passenger transport;
- Aviation passenger transport;
- Other transport;
- Service buildings;
- Other industry (all sectors with non-homogenous output).

***Countries*:** World.

***Emissions*:**

- ETP scenarios: $CO_2$ only;

- Other scenarios used include all Kyoto emissions: $CH_4$, $N_2O$, HFCs, Perfluorocarbons (PFCs), Sulfur hexafluoride ($SF_6$), and Nitrogen trifluoride ($NF_3$);

Focus scope 1 and 2 because under direct control. Scope 3 targets can be defined too.

***Analysis horizon and time steps*:** Depending on user-specific target year.

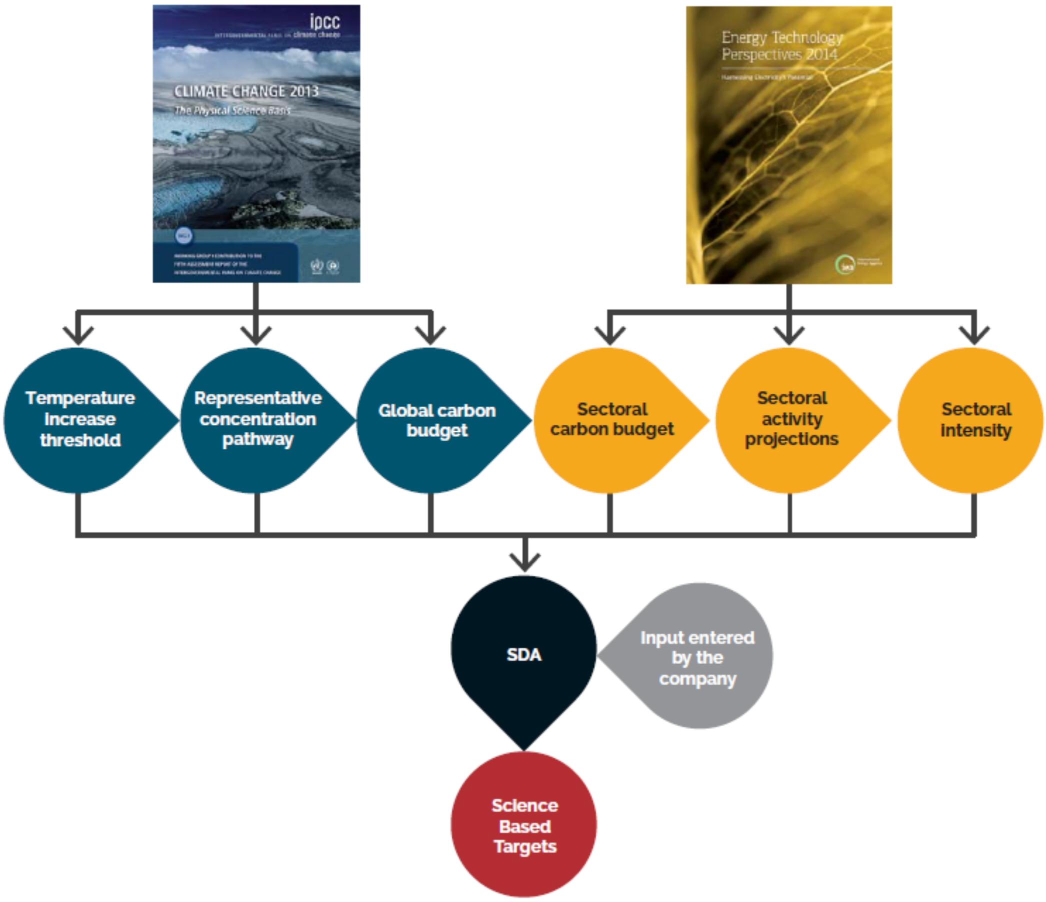


Figure 23: Model overview Science-based targets initiative - SBT Tool and SDA Transport Tool, *Source*: SBTi (2015).

| **Criteria-based tool analysis** | | SBTI |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | (x) | Code not publicly available, yet very detailed public model documentation online, see above in "Model Documentation" |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | User self-reported |
| b) Third party verified | - | User/company input (third party verification recommended but not required) |
| c) Missing data strategy explained | x | See `https://sciencebasedtargets.org/wp-content/uploads/2019/03/SBTi-criteria.pdf` and `https://sciencebasedtargets.org/wp-content/uploads/2019/04/target-validation-protocol.pdf` |
| **3. Science-based approach** | | |
| a) Scientific references | (x) | IAMC scenarios included in the IPCC Special Report on Global Warming of 1.5°C (SR15) |
| b) Peer-reviewed | x | SDA: published in Nature Climate Change: Krabbe et al. (2015) |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | IEA B2DS scenario |
| b) Country-differentiated | - | |
| c) Sector-differentiated | x | Analysis by sector, bottom-up models |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Broad GHG approach, identify most relevant scope per sector |
| b) Expected GHG emissions | n/a | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | n/a | |
| b) Peers performance, competition | n/a | |
| c) Cost pass-through | n/a | |
| **7. Adaptability** | | |
| a) Input substitution | n/a | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | = tool output | |
| **8. Economic impact** | | |
| a) Economic losses and gains | n/a | Economic or financial impacts as embedded in underlying scenarios (IEA ETP, IPCC SR15) |
| b) Macroeconomic development | n/a | " |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | n/a | " |
| b) Financial market amplification | n/a | " |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Scenarios from Integrated Assessment Modeling Consortium (IAMC) and IEA, key assumptions reported in documentation |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | - | Status quo |
| b) Scenario-neutral (various risk realisations) | (x) | SDA Transport: Choose between IEA 2DS / B2DS; SBT: more than 400 peer-reviewed emissions pathways incl. SSPs from IAMC; and IEA scenarios |
| c) Probability distribution input (timing) | n/a | |
| d) Probability distribution output (values) | (x) | Determine scenario envelope for comparison |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | - | |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | (x), dvp | Available for real economy sectors listed above; Method for financial institutions under development |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 37: Analysis Science-based targets initiative - SBT Tool and SDA Transport Tool

### S&P Global Market Intelligence - Climate Linked Credit Analytics

| | |
|---|---|
| **Full name** | Climate Linked Credit Analytics for Upstream Oil & Gas Companies (transition risk, fundamentals driven), alias CreditModel Energy Transition Risk Scenario Template |
| **Short name** | SPCM |
| **Owner** | S&P Global Market Intelligence - Credit Analytics |
| **Developer** | S&P Global Market Intelligence - Credit Analytics in consultation with Oliver Wyman |
| **Access** | Public, paywall, customized |

Table 38: Summary S&P Global Market Intelligence - Climate Linked Credit Analytics

Model Documentation: White paper available upon request

#### Key characteristics (Based on self-description)

S&P Global Market Intelligence, in consultation with Oliver Wyman[34], developed the Climate Linked Credit Analytics tool that enables investors and risk managers at banks and non-financial corporations to estimate the impact a the carbon tax on companies operating in an upstream Oil & Gas sector. The tool projects the impact of a carbon tax on a company's financial statements and evaluates the company's credit score.

The Climate Linked Credit Analytics tool adopts a bottom-up, fundamentals-driven approach, providing a company-specific credit score assessment for 1,200+ public and private upstream Oil & Gas companies on the Capital IQ platform. Four major drivers for the financial performance are identified for upstream Oil & Gas companies, that capture the impact of the climate-related scenarios: volume, price, unit cost, and capital expenditures. In the first step, they translate the impact of a climate scenario on these four drivers at an individual company level. Next, they derive the scenario-adjusted financials for each company and derive credit risk metrics to evaluate the change in credit quality (Vidovic and Baldassarri, 2019).

The scheme adopted is as follows: Carbon Tax Increase → Increased price of oil and gas → New market price and demand equilibrium based on supply and demand elasticities → Impact on firm's key performance drivers (Production costs, Operating Expenses, Revenues, Capital Expenditures) → Projected scenario-adjusted future financial statements (balance sheet, income statement, cash flow statement) → Impact on credit risk via fundamentals credit risk model (CreditModel™).

#### Model setup

***Output metrics*:**

- Full company-level financials statements (balance sheet, income statement, cash flow statement);
- Current and future Probability of Default;
- Current and future credit score;

[34] Oliver Wyman is a global management consulting firm and is not an affiliate of S&P Global, or any of its divisions.

- Absolute and relative contribution of credit risk factors.

***Output format*:** Excel template, linked to S&P Global Market Intelligence's Capital IQ Platform.

***Risk indicators*:**

- Economic climate risk indicators: Absolute emissions: Cost of emissions during Oil & Gas production; Cost of emissions that released when Oil & Gas products are used.

**Coverage**

***Transition risk sources:***

- Policy: Smooth (REMIND scenario), shock (abrupt introduction of carbon tax on Oil & Gas production); Adaptable to users' beliefs and expectations: possibility to incorporate other scenarios, users can change model assumptions and inputs;
- Market upstream: Smooth, shock; Via elasticity of demand and supply in Oil & Gas markets; Adaptable to users' beliefs and expectations;
- Market downstream: Smooth, shock; Via elasticity of demand and supply in Oil & Gas markets; Adaptable to users' beliefs and expectations;
- Technology: -
- Other: -

***Sectors*:** Oil & Gas production and exploration (further sectors under development).

***Countries*:** Global or regional scenarios.

***Emissions*:** $CO_2$ (scope 1-3), treated as a sum of cost of emissions generated during the production process and cost of emissions that will be released when Oil & Gas products are used (approach currently being expanded also to other sectors and materiality of other GHGs will be considered for those sectors).

***Analysis horizon and time steps*:** User can specify the starting year, the transition increase scenario and the year by which it will materialize. Default: 1-year time steps, 3-years horizon.

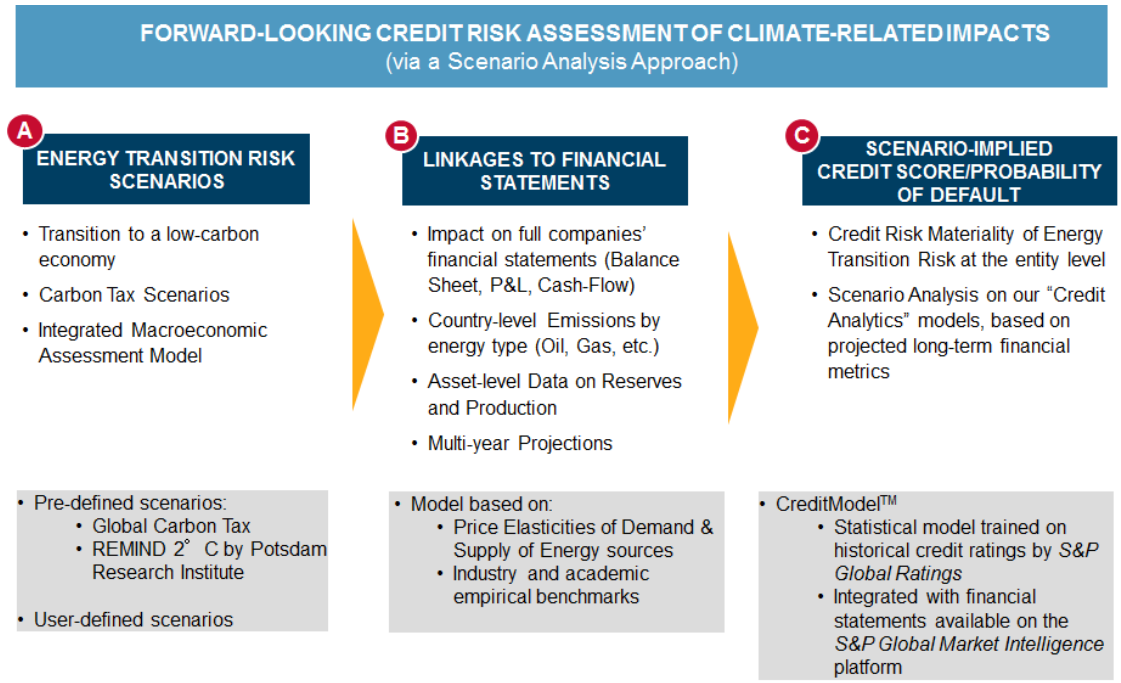


Figure 24: Model overview S&P Global Market Intelligence - Climate Linked Credit Analytics, *Source*: Presentation "The Credit Risk of Climate Change A Case Study on Energy Transition Risk", IACPM 2019 Spring Conference.

| **Criteria-based tool analysis** | | **SPCM** |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Tool user only, via excel-based template, including information on computational logic |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | EIA data, self-reported and own estimation: weighted average of upstream emissions by country of production, and production data per country (→ emissions generated during production); Additional data from third party provider: US EPA Greenhouse Gas Equivalencies Calculator (→ cost of emissions from oil and gas products) |
| b) Third party verified | - | Users can adjust emission values and associated costs |
| c) Missing data strategy explained | x | Comparative peer analysis |
| **3. Science-based approach** | | |
| a) Scientific references | (x) | Use REMIND 2°C by Potsdam Research Institute |
| b) Peer-reviewed | - | |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | (c) | Default: 2°C REMIND scenario; Further temperature scenarios can be accommodated within the tool |
| b) Country-differentiated | x | Company-level production quantity, costs and reserves by country/region |
| c) Sector-differentiated | x | Differentiate Oil & Gas, other sectors in development |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | only $CO_2$ for now, could be expanded to other GHG when applying this approach to other sectors we will review the materiality of GHGs. Note: (x) because does not cover methane, an important GHG in the gas sector |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | x | |
| b) Peers performance, competition | x | Transition-induced change within-sector competition (by leveraging REMIND scenario) |
| c) Cost pass-through | x | Demand elasticity can be adapted by user |
| **7. Adaptability** | | |
| a) Input substitution | - | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | - | |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, loss in revenues (via decrease in demand, increase in wholesale price); increase in production costs (via increase in production technology-related variable costs); Gains: Same as for losses, well covered in REMIND scenario |
| b) Macroeconomic development | x | Transition-induced change of economy's sectoral composition |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | (x) | If use REMIND: covers primary and secondary effects |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | (x) | Disclose assumptions and sources to users (white paper, detailed approach with formulas within Excel-based template) |
| b) Assumptions-based output communication | (x) | $CO_2$ price and further assumptions are displayed in tool; List REMIND scenario assumptions (users are referred to the PIK colleagues where assumptions are made available) |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (c) | Baseline is status quo |
| b) Scenario-neutral (various risk realisations) | (x) | User-specified $CO_2$ price or REMIND 2°C by PIK, other scenarios could be added |
| c) Probability distribution input (timing) | (x) | User can specify starting year, transition increase scenario and year by which it will materializes |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | - | Plausible via impairment of assets and reserves, however, this would require additional asset-level risk data |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | - | |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 39: Analysis S&P Global Market Intelligence - Climate Linked Credit Analytics

## S&P Global Market Intelligence - Climate Linked Credit Risk Tool

| | |
|---|---|
| **Full name** | Climate Linked Credit Risk Tool (transition risk, market driven), alias PD Model Market Signals Energy Transition Risk Scenario Template |
| **Short name** | SPPD |
| **Owner** | S&P Global Market Intelligence - Credit Analytics |
| **Developer** | *same as owner* |
| **Access** | Public, paywall, customized |

Table 40: Summary S&P Global Market Intelligence - Climate Linked Credit Risk Tool

Model Documentation: White paper, available to potential clients upon request.

### Key characteristics (Based on self-description)

Climate Linked is a market-driven credit risk tool. The tool leverages Trucost's extensive database of $CO_2$ emissions at company level and projects future market capitalization of public companies globally, based on pre- or user-defined scenarios. Future market capitalization is then used within S&P Global Market Intelligence's PD Model Market Signals, a market-driven probability of default model, to determine the change in creditworthiness of those companies (Baldassarri et al., 2020).

The scheme adopted is as follows: Carbon Tax Increase → Carbon Emission Costs increase → Impact on firm's (Operating Expenses, Revenues, company earnings, market capitalization) → Impact on credit risk via structural Merton model.

### Model setup

***Output metrics*:**

- Company-level current and future earnings;
- Current and future market capitalization;
- Current and future distance to default
- Current and future PD;
- Change in credit score from current to future year (expressed in notches).

***Output format*:** Excel template, linked to S&P Global Market Intelligence's Capital IQ Platform.

***Risk indicators*:**

- <u>Climate-adjusted financial risk indicator</u>: PD and credit score calculated using future market capitalization, calculated by aid of the model setup;
- <u>Economic climate risk indicators</u>: Absolute emissions, assessed against the following metric: $tCO_2e$ (scope 1 and 2) provided by Trucost; Emission intensity, using the following metric: $tCO_2e$/USD (scope 1 and 2) provided by Trucost;
- Peer comparison, namely: average emission intensity for companies in same industry sectors;
- Transition readiness, namely: CAPEX;

- Other: estimated abatement costs to achieve certain emission reduction target (consistent with 2°C scenario).

Scope 3 emissions can be accommodated.

**Coverage**

***Transition risk sources:***

- Policy: Smooth, shock; Two options: 1) Carbon tax is increased with slow, moderate or fast speed to meet COP21 targets (slow) or 2°C target (moderate and fast) 2) Governments force companies to reduce emissions by restricting use of carbon emission-intensive technology/materials; Adaptable to users' beliefs and expectations;
- Market upstream: -
- Market downstream: -
- Technology: Smooth, shock (customized); Via abatement costs to adopt new technology;
- Other: -

***Sectors*:** All; Company-specific assessment for 44,000+ public (financial and non-financial) companies.

***Countries*:** World, by country.

***Emissions*:** $CO_2$ (scope 1-2, scope 3 optional); All other GHGs feasible if user transforms other GHGs into $CO_2$e.

***Analysis horizon and time steps*:** 1-year time steps: 2020-2025; 5-year time steps: 2025-2050.

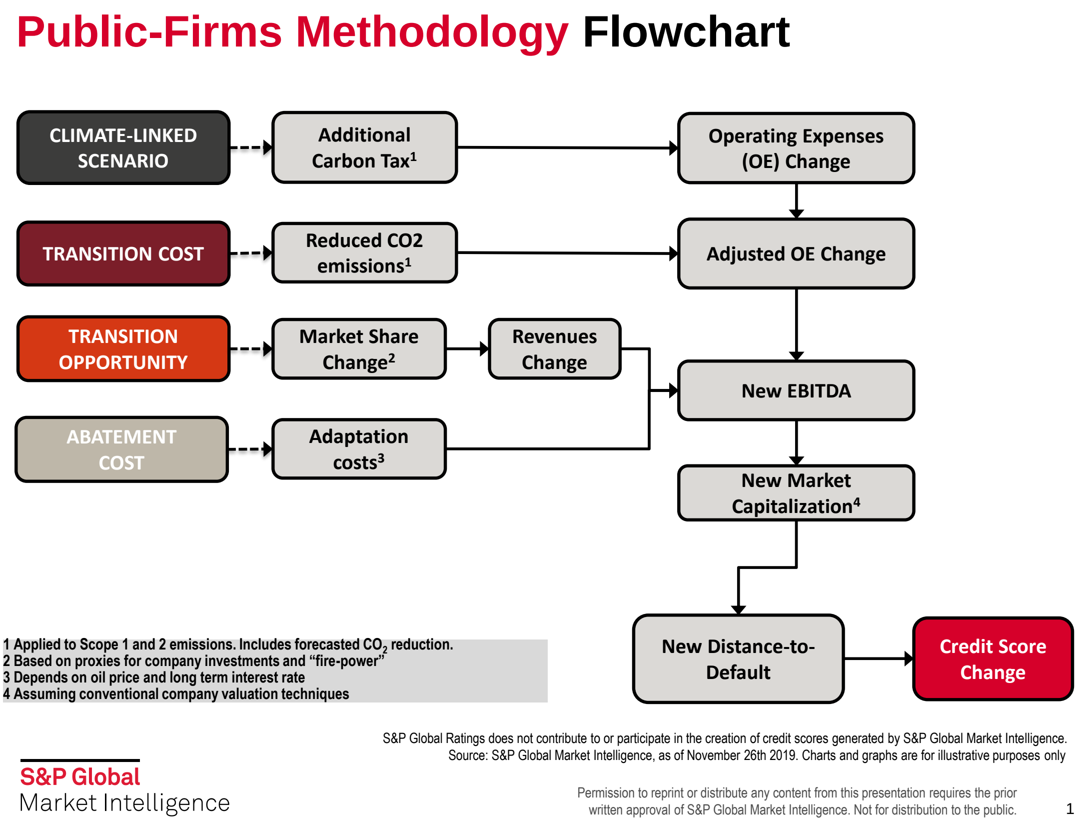


Figure 25: Model overview S&P Global Market Intelligence - Climate Linked Credit Risk Tool, *Source*: Presentation "Carbon Pricing Paths to a Greener Future and Potential Roadblocks to Public Firms Creditworthiness", CREDIT 2019, Venice, September 26 27, 2019.

| Criteria-based tool analysis | | SPPD |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | White paper available upon request; Detailed approach with equations in Excel-based template for users only |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Estimated, by third party provider Trucost |
| b) Third party verified | (x) | From Trucost - reported by companies, and estimated by Trucost (when not reported); Carbon emission abatement costs from estimates by McKinsey for 2° target; Tool allows clients to edit emission values and explore impact analysis on model outputs |
| c) Missing data strategy explained | x | Proxied via $CO_2$ emissions per USD revenue amount from comparable companies (same country/industry) |
| **3. Science-based approach** | | |
| a) Scientific references | - | |
| b) Scientific process | x | Academic paper describing methodology of an earlier version of the tool in Risk.Net "Journal of Energy Markets" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2° scenario | (c) | Tool itself does not employ scenarios, but inputs on emission and cost projections for various scenarios from McKinsey and Trucost. Projections: Paris Agreement INDC; Further temperature-related scenarios can be easily accommodated, upon request |
| b) Country-differentiated | x | Carbon price risk for company differentiated by geographical distribution of company's emissions (by country and sector) |
| c) Sector-differentiated | x | Carbon price risk for company differentiated by sectoral distribution of company's emissions (by country and sector) |
| **5. Exposure** | | |
| a) Current GHG emissions | x | Cover all GHG emissions, transformed as $CO_2e$ |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | Carbon emissions abatement costs are calculated based on the McKinsey analysis; These could reduce profits |
| b) Peers performance, competition | x | Reallocation of "revenue pot" among companies in same sector |
| c) Cost pass-through | x | Differentiated price elasticity by four industry groups that companies in same industry try to pass to their consumers |
| **7. Adaptability** | | |
| a) Input substitution | - | Not allowed, since demand price elasticity is modelled at industry sector level |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | x | Ability to adopt greener technologies (reflected in current CAPEX - all CAPEX for now, will be refined by green CAPEX as soon as Trucost makes green CAPEX data available). Optional: include carbon tax savings from future emission reductions |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in revenues (asset stranding due to policies to restrict use of carbon-intensive technologies/ materials/ fuels), increase in production costs (increase in input prices, abatement costs to adopt new technology); Gains: Increase in revenues: reallocation of "revenue pot" among companies in same sector. Optional: Carbon price expenditure savings due to future emission reductions |
| b) Macroeconomic development | (x) | Separate model to assess macro-economic impact of typical macro-economic variables, such as real GDP growth, house price index, etc. |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | - | |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Paying users can see all inputs, drivers and formulas and final outputs |
| b) Assumptions-based output communication | (x) | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | (c) | Comparisons against status quo; Default baseline scenario (if required): Paris-implementation (3°) |
| b) Scenario-neutral (various risk realisations) | (x) | Either user-defined uniform global carbon tax, or Trucost scenario data over slow (3°, NDC implementation), moderate (2°, slow onset and strong policy increase afterwards) and fast (2°, seven-fold increase in the current average price of carbon, to achieve around USD 120/$tCO_2$ by 2030 in OECD countries (Baldassarri et al., 2020) |
| c) Probability distribution input (timing) | x | User can specify carbon tax increase scenario and year by which it will materializes |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs. Offer whole distribution as well as granular results, at company level |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | dvp | Separate tool that leverages risk scenarios impacts provided by Bank of England (e.g. within annual stress testing); Trucost's asset level data and physical risk assessments |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | - | |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 41: Analysis S&P Global Market Intelligence - Climate Linked Credit Risk Tool

## University of Augsburg - CARIMA

| | |
|---|---|
| **Full name** | Carbon Risk Management (CARIMA) |
| **Short name** | UNIA |
| **Owner** | Prof. Dr. Marco Wilkens, Chair of Finance and Banking, University of Augsburg |
| **Developer** | *same as owner* |
| **Access** | Public, free access |

Table 42: Summary University of Augsburg - CARIMA

Model Documentation: See Hyperlink CARIMA Online Documentation, construction of the Carbon Risk Factor BMG described in Görgen et al. (2019).

### Key characteristics (Based on self-description)

Görgen et al. (2019) quantify the "carbon risk" via a "Brown-Minus-Green (BMG) factor". To construct BMG, the author use detailed carbon and transition-related information for over 1,600 globally listed firms filtered from four major ESG databases and categorize these firms as brown or green using an annual "Brown-Green-Score" (BGS). The BGS is a composite measure of three indicators designed to separately capture the sensitivity of firms' "value chains" (e.g. current emissions), of their "public perception" (e.g., response to perceived emissions), and of their "adaptability" (e.g., mitigation strategies) to carbon risk. The BMG can be added to all traditional factor models (e.g. CAPM, Carhat Model etc.) and tests show that the BMG significantly increases the explanatory power of common asset pricing models, suggesting that it is equally important in explaining variation in global equity prices as the size factor. The BGS allows estimating an applicable measure of carbon risk: "Carbon beta", which measures the stock value decrease or increase in comparison to other stocks if the transition process is unexpectedly changing. The author compute carbon betas for 39,000 firms and report them for countries and sectors. To measure the carbon risk of firms without primary carbon or transition-related information, Görgen et al. (2019) run time-series regressions explaining firms' excess returns using an extended Carhart model. The Carbon beta $\beta_i^{BMG}$ is thus a capital market-based measure of carbon risk that captures the sensitivity of a firm to carbon risk. Positive values represent "brown" firms, which are likely to be affected by carbon risk in the transition process towards a Green Economy. They also report average Carbon betas by country and industry. Carbon betas are high and positive in countries like South Africa, Brazil, and Canada, which means they are likely to be negatively affected if the world speeds up the transition to a low-carbon economy. Contrarily, average carbon betas are negative in European countries and Japan. On the industry level, tech firms have carbon betas near zero on average, while basic material and energy firms have the highest positive carbon betas as expected. There are, however, significant differences in Carbon betas within industries. Finally, the authors show that carbon risk is related to firm characteristics independent of their industry. Firms investing in innovation and clean technology, proxied by R&D expenditures, have lower Carbon betas while firms with dirty or "stranded" assets, proxied by property plant and equipment (PPE) assets, have higher carbon betas.

**Model setup**

***Output metric*:** Carbon beta (relative measure for carbon risk, no unit).

***Output format*:** Excel file with figures, tables and application examples.

***Risk indicator*:**

- Climate-adjusted financial risk indicator: Carbon beta (a positive value of carbon beta indicates a portfolio with a high proportion of brown corporate securities that is more volatile and therefore riskier during the transition process towards a Green Economy);
- Economic climate risk indicator: Firm-level determinants of brown or green: Sensitivity of firms' "value chains" (e.g., current emissions), of their "public perception" (e.g., response to perceived emissions), and of their "adaptability" (e.g., mitigation strategies) to carbon risk → 55 carbon and transition related data variables, including emission intensity.

**Coverage**

***Transition risk sources:*** Capital market expectations-based. These could include:

- Policy: Carbon tax, carbon pricing or other regulation, Paris Agreement-like events;
- Market upstream: n/a;
- Market downstream: Change in consumer behavior towards green products;
- Technology: Green technologies;
- Other: Divestment.

***Sectors*:** All.

***Countries*:** World.

***Emissions*:** $CO_2$, $CH_4$, $N_2O$, $O_3$, CFCs, HCFCs, HFCs (all scope 1 and 2).

***Analysis horizon and time steps*:** Fully flexible; Various, since investor expectation based (no simulation of one shock/trajectory event).

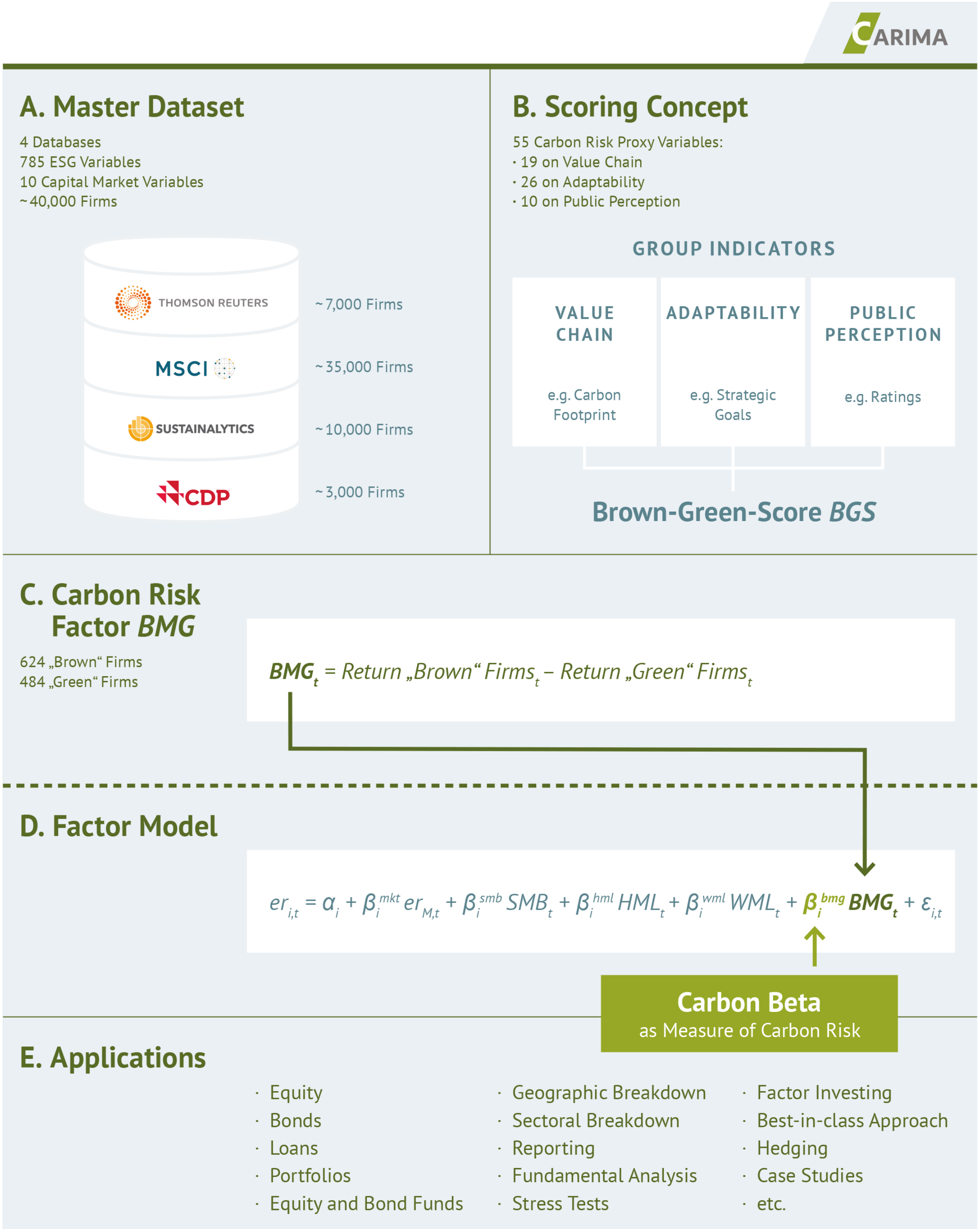


Figure 26: Model overview University of Augsburg - CARIMA, *Source*: Wilkens et al. (2019)

| **Criteria-based tool analysis** | | UNIA |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | x | The latest version of the CARIMA Excel Tool is available on request by e-mail, very detailed public model descriptions: See "Model Documentation |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Self-reported and third-party verified, using the following sources: CDP, Thomson Reuters/Refinitiv ESG, MSCI ESG, Sustainalytics |
| b) Third party verified | x | Use four different data providers, control for outliers and check manually |
| c) Missing data strategy explained | x | Around 85% of market capitalization firms is covered; Drop the firm from analysis if no emission data available |
| **3. Science-based approach** | | |
| a) Scientific references | x | |
| b) Peer-reviewed | x | See above "Model Documentation" |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | - | Not scenario-based and not based on temperature limit considerations, based on market expectations about the transition process and future temperature limits to be achieved |
| b) Country-differentiated | - | Not necessary as investor expectations reflected in asset price |
| c) Sector-differentiated | - | Not necessary as investor expectations reflected in asset price |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | Not explicit materiality assessment, implicitly the materiality assesments of the data providers and the evaluation of the capital market are used to ensure that most risk-relevant GHGs are covered |
| b) Expected GHG emissions | (x) | If reflected in asset price (depends on the evaluation of the capital market) |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | (x) | " |
| b) Peers performance, competition | (x) | " |
| c) Cost pass-through | (x) | " |
| **7. Adaptability** | | |
| a) Input substitution | (x) | " |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | (x) | " |
| **8. Economic impact** | | |
| a) Economic losses and gains | (x) | " |
| b) Macroeconomic development | (x) | " |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | (x) | " |
| b) Financial market amplification | x | Financial market-based valuation, hence as soon as expectation revisions are reflected in asset prices |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Description of assumptions and possibilities to adapt them in the manual. General assumptions regarding the use of factor models are also briefly considered |
| b) Assumptions-based output communication | - | |
| **11. Uncertainty** | | |
| a) Baseline adaptable | - | Status quo |
| b) Scenario-neutral (various risk realisations) | - | Reflects market expectations about the transition process |
| c) Probability distribution input (timing) | - | The Carbon Risk measure Carbon beta represents the average evaluation of all capital market participants when a risk materializes for a specific firm. Therefore, it is externally specified, cannot be determined to a specific year and cannot be selected by a user |
| d) Probability distribution output (values) | - | |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | - | |
| b) Trade-off physical-transition risks | - | |
| **Climate targets** | | |
| a) Alignment assessed | - | |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 43: Analysis University of Augsburg - CARIMA

## Vivid Economics - Climate Risk Toolkit

| | |
|---|---|
| **Full name** | Climate Risk Toolkit |
| **Short name** | VIVE |
| **Owner** | Vivid Economics |
| **Developer** | *same as owner* |
| **Access** | Public, paywall, customized |

Table 44: Summary Vivid Economics - Climate Risk Toolkit

Model Documentation: Much of the work is confidential. Publicly available examples: Hyperlinks VividEconomics Online Documentation, Transition risk module documentation (also called "Net Zero Toolkit") published as part of the work with HSBC and Transition risk module documentation as part of the Inevitable Policy Response (IPR) work. Previous physical risk analysis for ClimateWise on real estate lending and investment portfolios in the United Kingdom: Hyperlink Online documentation.

### Key characteristics (Based on self-description)

The Climate Risk Toolkit uses scenario analysis and microeconomic modeling to quantify the transition and physical risk impacts of disruptive climate policy on financial markets. The starting point of the analysis is bottom-up, with the asset level used when possible and otherwise other security level. Climate scenarios are tailored to a client's portfolio or view of future climate policy and are developed using macroeconomic, energy system and land use models (See Hyperlink: VividEconomics Online Documentation). It offers clients the ability to alter the analysis to their needs, and to disaggregate impacts across a variety of impact channels. The tool produces insights on climate transition-related financial risks for investors, asset managers, banks, insurers, private equity firms, and regulators.[35]

The toolkit incorporates various exposure channels including changes in fossil fuel and mineral demand, cleantech deployment, carbon prices, labour and agricultural productivity, and the incidence of extreme weather events. Alongside exposure channels, economic responses (emissions abatement and adaptation to physical risks), and competitiveness implications are factored in. This produces a picture of climate risk impacts at the asset class, subclass and asset level, as shown in the IPR FPS equity results. The Climate Risk Toolkit also offers clients the ability to create bespoke scenarios that best reflect their views given policy, technology and physical uncertainties. The scenario modelling has been developed in partnership with academic institutions to ensure sophistication and flexibility.

The toolkit is used by clients as part of:

1. TCFD disclosure and temperature alignment: analysing existing portfolios to provide financial risk metrics and a temperature alignment metric for public reporting

2. Regulatory stress-testing for banks and insurers: analysing loan books and other holdings in line with the Bank of England's 2021 Biennial Exploratory Scenario

[35] Among the publicly announced projects, Vivid has worked recently with Invesco, HSBC Global Asset Management, and Lloyds of London, as well as with various industry-leading groups such as the PRI, IIGCC, ClimateWise, ACSI and UNEP-FI.

3. Scenario analysis for risk management: using bespoke climate scenarios to better understand the probability distribution of risk, including different policy, technology and physical risk pathways over time

**Model setup**

***Output metrics*:** Outputs vary by asset class, but are generally provided in terms of valuation impacts – percentage change in valuation under given climate scenario compared to reference scenario.

***Output format*:** :Flexible with various delivery options depending on client needs:

- Data files in csv, xml, or other format
- Written reports in pptx or doc formats
- web-based delivery to explore the data

***Risk indicators:***

- Climate-adjusted financial risk indicator: Percentage change in valuation under the given climate scenario;
- Economic climate risk indicators: Emission intensity, using the following metric: Scope 1, 2 and 3 emissions translated into future cash flow impairments, factoring in exposure, response (such as abatement and cost pass through) and competition/market impacts;
- Peer comparison: Market dynamics are taken into account; Cost pass through capacity depends on company relative emissions intensity and sector characteristics;
- Transition readiness: Abatement potential, based on sector-region abatement cost curves.

**Coverage**

***Transition risk sources:***

- Policy: Smooth, shock; Depending on scenario; various policy narratives in bespoke scenarios; Adaptable to users' beliefs and expectations;
- Market upstream: Smooth, shock; Scope 2 emissions (increased electricity costs) are considered across scenarios. Scope 3 emissions (upstream) are translated into increase input costs across scenarios; Adaptable to users' beliefs and expectations;
- Market downstream: Smooth, shock; Depending on scenario; Considered for the following sectors analyzed: Oil, gas and coal extraction and related downstream activities, automobile manufacturing and related downstream activities (ICE, ULEV), renewable energy equipment manufacturing, "green" minerals and metals extraction (defined as those needed as inputs for low carbon technologies: cobalt, copper, lithium, nickel and silver (ore)); Adaptable to users' beliefs and expectations;
- Technology: Smooth, shock; Technology shocks can be modeled through inhouse energy system models or through the use of off the shelf scenarios. Vivid can explore various technology narratives in bespoke scenarios (such as "cheap CCS from 2030") and ensure energy system consistency using inhouse models; Adaptable to users' beliefs and expectations;

- Other: -

Note from Vivid: Design of bespoke scenarios in collaboration with Imperial College London academics and other modelling institutions. They also cover chronic (reduced labour productivity and agricultural yields) and a acute physical risks (changes in average annual damages from extreme weather events). Physical risk scenarios are defined and aligned to transition risk scenarios by a GHG emissions pathway. Vivid can (and has previously) also run the Climate Risk Toolkit using publicly available scenarios.

***Sectors*:** All.

***Countries*:** World, and specific countries (Analysis can be broken out for all individual countries).

***Emissions*:** $CO_2$, $CH_4$, $N_2O$ (all scope 1-3).

***Analysis horizon and time steps*:** Fully flexible, 1-year time steps.

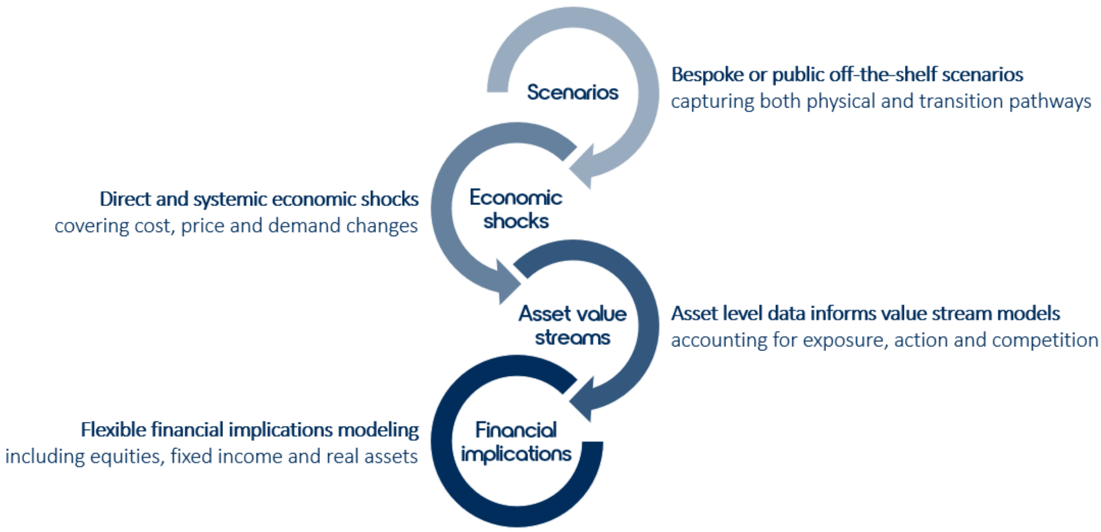


Figure 27: Simplified model overview Vivid Economics - Climate Risk Toolkit

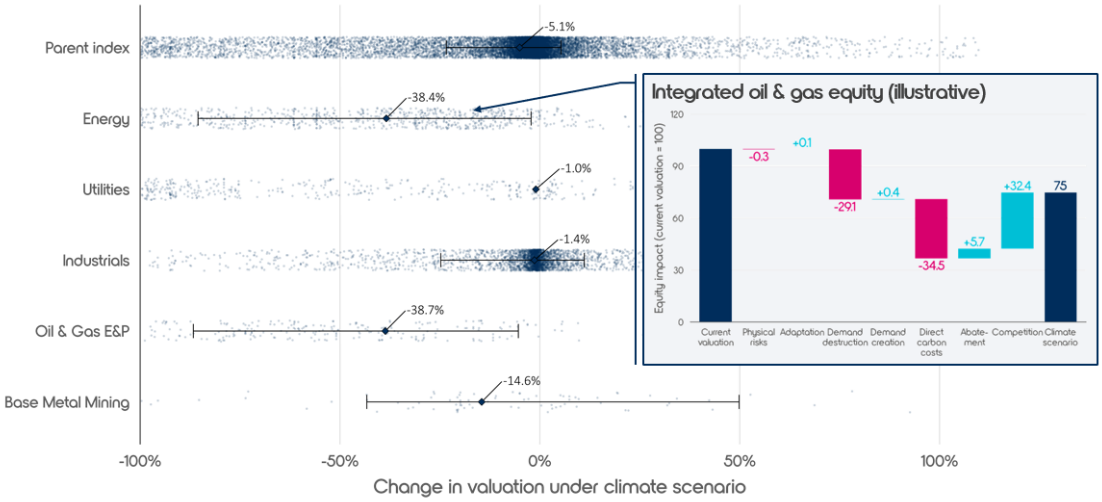


Figure 28: Example output Vivid Economics - Climate Risk Toolkit

| **Criteria-based tool analysis** | | **VIVE** |
|---|---|---|
| **Criterion** | *) | **Tool setup** (self-reported) |
| I. ACCOUNTABILITY | | |
| **1. Public transparency** | | |
| a) Model modules, code | - | Detailed method documents for clients, only |
| b) Study questionnaire completed | x | |
| **2. Emission data strategy** | | |
| a) Data sources reported | x | Estimated, by third party provider: Trucost or CDP; Self-reported, not third-party verified, for non listed equities or other asset classes without public data available; Client-reported data |
| b) Third party verified | (x) | See element 2a), adjust for outlayers |
| c) Missing data strategy explained | x | Can use proxy portfolios or assets based on similar characteristics (e.g. sector-region) |
| **3. Science-based approach** | | |
| a) Scientific references | x | Work directly with climate modelling institutions, including Imperial College London academics |
| b) Peer-reviewed | (x) | Work mostly with peer-reviewed underlying models (e.g. TIAM) |
| II. DEPTH OF RISK ANAYLSIS | | |
| **4. Hazard (shock / smooth transition)** | | |
| a) 1.5/<2°C scenario | x | Bespoke scenarios and publicly available scenarios |
| b) Country-differentiated | x | All impacts can be broken down by country and impact channel |
| c) Sector-differentiated | x | |
| **5. Exposure** | | |
| a) Current GHG emissions | (x) | Rely on third party data providers' assessments |
| b) Expected GHG emissions | x | |
| **6. Vulnerability & Resilience** | | |
| a) Profits to cover costs | x | Direct cost impact |
| b) Peers performance, competition | x | Competition modelled |
| c) Cost pass-through | x | |
| **7. Adaptability** | | |
| a) Input substitution | x | |
| b) Climate strategy, climate-aligned R&D or future CAPEX plans | (x) | Could adjust input assumptions to account or test for the impacts of changed corporate strategy |
| **8. Economic impact** | | |
| a) Economic losses and gains | x | Loss in profits, loss in revenues (decrease in demand, increase in wholesale prices), increase in production costs (increase in input prices, in production technology-related fix and variable costs); Gains: Inverse from losses |
| b) Macroeconomic development | x | |
| **9. Risk amplification** | | |
| a) Mutual risk amplification | - | |
| b) Financial market amplification | - | |
| III. USABILITY | | |
| **10. Output interpretability** | | |
| a) Model structure, scenarios and assumptions reported | x | Communicated in final reports/ method documentation for clients |
| b) Assumptions-based output communication | x | Model documentation (incl. assumptions etc.) and description/interpretation of findings always part of engagements |
| **11. Uncertainty** | | |
| a) Baseline adaptable | x | Can be any off-the-shelf scenario or a bespoke scenario modelled using Vivid's in-house scenario design tool which allows users to test their own assumptions. Vivid decides the reference scenario depending on what clients believe current valuations to be centred on. The Toolkit has previously used "No New Action" (existing climate policies only) and "Paris NDCs" (fulfilment of current NDCs) scenarios as the baseline/reference (in HSBC and IPR work). |
| b) Scenario-neutral (various risk realisations) | x | Can be any off the shelf or bespoke as modelled using Vivid's inhouse scenario design tool. Offer clients the design of bespoke scenarios drawing on leading academic climate models. This approach designs a transition scenario narrative that enable clients to test their own technology and policy assumptions. Physical risk scenarios are then defined and aligned to these transition risk scenarios by a greenhouse gas emissions pathway. Vivid can (and has previously) also run the Toolkit using publicly available scenarios including the IEA and NGFS scenarios. |
| c) Probability distribution input (timing) | (x) | Flexible; Standard output: NPV effects today, but flexible to evaluate impact for all years to 2050 on customized basis |
| d) Probability distribution output (values) | (c) | Output itself not based on probability distribution, but could run the model multiple times with different scenarios and/or assumptions to generate a probability distribution of various outputs |
| FURTHER USE | | |
| **Physical risks** | | |
| a) Physical risks covered | x | Combined or separate climate risk indicator / analysis output, can construct physical risk scenarios consistent with bespoke transition scenarios. Modelled physical risks include higher incidence of extreme weather events and slow onset physical risks such as agricultural and labour productivity effects. The two risk impacts can be aggregated as all costs are run through the "cost & competition" model, which examines cost impacts in the context of each market. However, the individual components of the total impact can also be disaggregated so the contribution of physical and transition risk is clear |
| b) Trade-off physical-transition risks | x | See element a) |
| **Climate targets** | | |
| a) Alignment assessed | x | The Climate Risk Toolkit also includes temperature alignment analysis at a portfolio or fund level; these metrics can be provided alongside financial risk assessment results. |
| b) Financial institution impact analysis | - | |

*) Analysis: x fulfilled — (x) partially fulfilled — (c) only in customized approach — - not fulfilled — n/a not applicable — . information not available or confidential — dvp under development

Sources: Study questionnaire, tool documentation

Table 45: Analysis Vivid Economics - Climate Risk Toolkit

# B Study questionnaire

The following pages document the questionnaire preamble and the questions, that have been developed for the analysis and have been answered by the tool providers.

ETH Climate risk indicator study

# Questionnaire for tool provider

First, thank you very much for participating in this study. This is very highly appreciated.

Overall, the questionnaire consists of 3 Parts. Part I is about the general tool setup, Part II is about the underlying economic model and financial use cases, and Part III is about the driver of analysis. **Feel free to split the questionnaire in the team and let different people answer the questions, depending on their expertise.**

This questionnaire can be answered in approximately 1.5 - 3 hours. If this is too long, we allow for several options to reduce the amount of time spent on the survey:

In general, most questions can be answered by simply ticking boxes. Furthermore, in almost all questions, we allow for the **option "do not know"** (= "Do not know for the moment – would have to ask specialist"). **For information that is not readily available, you can tick this box and we might get back to you at a later point in time** to ask for the specific information, if required.

If you still feel that the questionnaire is too long, we recommend to pursue as follows:

1. If you are very limited in time, you could just fill in the basic information as asked for in Part I. **Filling in part I ensures you will be explicitly listed in the publication's longlist of promising climate risk tools.**
2. If you could devote slightly more time to the questionnaire, it would be great if you then answer Part II. This part is key for our matching of tools and use cases. **If you fill in part II, your tool will be matched with at least one use case.**
3. Eventually, **filling in part III ensures your tool will be analysed alongside all important criteria, and to gain additional credits for transparency.**

It would be great to get your responses **by 20 December 2019**. However, if this would not work for you, we are more than willing to discuss options to adapt to your schedule.

Again, thank you very much for filling in the questionnaire and for your general support of our study.

If you have any questions, please do not hesitate to get in touch:

Julia Anna Bingler

Researcher at Center of Economic Research, ETH Zurich

Mail: binglerj@ethz.ch

Phone: +41 44 632 51 10

# Questionnaire tool analysis

| Basic information | |
|---|---|
| Tool full name | *[Please insert full name and abbreviation]* |
| Developer | *[Please state the initial tool developer]* |
| Owner | *[Please state the tool owner, if different from the developer]* |
| Documentation | *[Please provide a link to the full tool documentation, as publicly available]* |
| Contact Person for further questions | *[Please insert Name, Email, Phone number]* |

## PART 1 – General Setup (approx. 30-60 minutes)

| Tool output and general setup | |
|---|---|
| Tool output metric | *[Please specify, e.g. USD at risk]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Tool output format | *[Please specify, e.g. report in PDF format with output metrics figures and verbal analysis / excel file with figures on the output metrics, etc]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Specific climate transition risk exposure indicator** used for analysis / provided as result of analysis<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate box/es:]*<br>Indicator is based on<br>☐ Absolute emissions, assessed against the following metric: *[Please specify]*<br>☐ Emission intensity, using the following metric: *[Please specify]*<br>☐ Production capacity emissions, namely: *[Please specify]*<br>☐ Peer comparison, namely: *[Please specify compared entities and metric of comparison]*<br>☐ Transition readiness, namely: *[Please specify]*<br>☐ Other: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |

| | |
|---|---|
| **Starting unit of analysis used** by the tool<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>☐ Project, namely: *[Please specify]*<br>☐ Production capital asset<br>☐ Real estate asset<br>☐ Company / Company's business model<br>☐ Sector-averages<br>☐ Municipality<br>☐ Country / State<br>☐ Other: *[Please specify]*<br><br>☐ Under development: *[Please specify which units of analysis are under development, including Q/year by which you expect these to be ready]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Output unit of analysis provided** by the tool<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>☐ Project, namely: *[Please specify]*<br>☐ Production capital asset<br>☐ Real estate asset<br>☐ Company / Company's business model<br>☐ Sector-averages<br>☐ Municipality<br>☐ Country / State<br>☐ Other: *[Please specify]*<br><br>☐ Under development: *[Please specify output units are under development, including Q/year by which you expect these to be ready]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Financial instruments** for output units as analysed by the tool<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>Individual financial assets:<br>☐ Stocks<br>☐ Bonds, namely: *[Please specify bond classes, e.g. government bonds]*<br>☐ Loans, namely: *[Please specify loan classes, e.g. corporate loans]*<br>☐ Credits, namely: *[Please specify credit classes, e.g. private credits]*<br>☐ Options and Derivatives<br>☐ Other/further: *[Please specify]*<br>☐ None specified to date<br><br>Aggregated financial assets:<br>☐ Portfolios<br>☐ Funds<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Temperature limit** considerations<br><br>☐ do not know<br>☐ can not disclose | *[Please tick appropriate boxes:]*<br>☐ 1.5°C<br>☐ below 2°C<br>☐ 2°C<br>☐ > 2°C - 3°C |

| | |
|---|---|
| ☐ user-specific | ☐ > 3°C - 4°C<br>☐ > 4°C<br>☐ Other: *[Please specify]*<br>☐ Not based on temperature limit considerations<br><br>☐ *confidential information, please ask for permission if want to publish* |
| General approach and baseline<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>Does the tool use forward-looking analyses to estimate climate risk?<br>☐ Yes,<br>  ☐ scenario-based<br>  ☐ based on qualitative reasoning<br>  ☐ Other: *[Please specify]*<br>☐ No, it is based in status quo / analysis of backward-looking data, only<br>☐ A combination of both, i.e.: *[Please specify]*<br>☐ Depends on specific output (if one tool provides multiple outputs), i.e.: *[Please specify]*<br>☐ Other: *[Please specify]*<br><br>Baseline, against which the future developments/events are assessed:<br>☐ Baseline starting point assumptions based on:<br>  ☐ Status quo<br>  ☐ Business as usual, with the following key assumptions: *[Please specify]*<br>  ☐ Other: *[Please specify]*<br>☐ Baseline trend assumptions based on:<br>  ☐ Status quo<br>  ☐ Business as usual, with the following key assumptions: *[Please specify]*<br>  ☐ Other: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Model scheme<br><br>☐ do not know<br>☐ can not disclose | *[Please provide a very short schematic description of the model (verbal or graphic), e.g. "Type of Input -> Development/event considered -> Economic Impact assessed -> Financial Impact assessed -> Tool output"]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Comments:<br><br>☐ *confidential information, please ask for permission if want to publish* | |

<table>
<tr><th colspan="2">Specific transition risk sources</th></tr>
<tr><td rowspan="5">Risk sources considered: Climate-related smooth developments and/or shock events<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific</td><td>[Please tick the appropriate boxes:]<br><br>☐ Policy<br>☐ smooth / “ordered transition”<br>☐ shock / “disruptive”<br>namely: [Please state the event/development considered, e.g. the policy instrument introduced]<br><br>☐ Applies to all sectors analysed<br>☐ Considered for the following sectors analysed: [Please specify]<br><br>☐ Adaptable to users’ beliefs and expectations</td></tr>
<tr><td>☐ Market upstream (supply chain),<br>☐ smooth / “ordered transition”<br>☐ shock / “disruptive”<br>namely: [Please state the event/development considered]<br><br>☐ Applies to all sectors analysed<br>☐ Considered for the following sectors analysed: [Please specify]<br><br>☐ Adaptable to users’ beliefs and expectations</td></tr>
<tr><td>☐ Market downstream (demand),<br>☐ smooth / “ordered transition”<br>☐ shock / “disruptive”<br>namely: [Please state the event/development considered]<br><br>☐ Applies to all sectors analysed<br>☐ Considered for the following sectors analysed: [Please specify]<br><br>☐ Adaptable to users’ beliefs and expectations</td></tr>
<tr><td>☐ Technology<br>☐ smooth / “ordered transition”<br>☐ shock / “disruptive”<br>namely: [Please state the event/development considered]<br><br>☐ Applies to all sectors analysed<br>☐ Considered for the following sectors analysed: [Please specify]<br><br>☐ Adaptable to users’ beliefs and expectations</td></tr>
<tr><td>☐ Other: [Please specify]<br>☐ smooth / “ordered transition”<br>☐ shock / “disruptive”<br>namely: [Please state the event/development considered]<br><br>☐ Applies to all sectors analysed</td></tr>
</table>

<table>
<tr><td></td><td>☐ Considered for the following sectors analysed: [Please specify]<br><br>☐ Adaptable to users' beliefs and expectations</td></tr>
<tr><td></td><td>☐ confidential information, please ask for permission if want to publish</td></tr>
<tr><td>Amplification of various risk sources</td><td>Does the tool allow for amplification mechanisms and self-enforcing dynamics of various risk sources?<br>☐ Yes<br>☐ No<br><br>If so, which mechanisms are considered? [Please specify, e.g. technology development in area XX makes more stringent climate policy ZZ more likely]<br><br>☐ confidential information, please ask for permission if want to publish</td></tr>
<tr><td>Differentiation by country and sector<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific</td><td>[Please tick the appropriate boxes:]<br>Could you differentiate the types and impacts of considered risk sources by countries?<br>☐ Yes, as follows: [Please specify]<br>☐ No<br><br>Do you differentiate the specific realisation of the same risk sources by sector?<br>☐ Yes: [Please specify]<br>☐ No<br><br>☐ confidential information, please ask for permission if want to publish</td></tr>
<tr><td>Combination physical risks and transition risks<br><br>☐ do not know<br>☐ can not disclose</td><td>[Please tick the appropriate box:]<br>Does the tool combine physical and transitory climate-related risks?<br>☐ Yes,<br>☐ transition and physical risks are combined into a combined climate risk indicator / analysis output<br>☐ transition and physical risks are both analysed and provided as separate risk indicators / separate analysis output<br>☐ Not yet, but extension to include physical risks is under development, as follows: [Please specify]<br>☐ No,<br>☐ but following extension for physical risks would be feasible: [Please specify]<br>☐ including physical risks in the analysis would be very challenging / not feasible to date<br><br>☐ confidential information, please ask for permission if want to publish</td></tr>
<tr><td>Combination climate targets alignment analysis<br><br>☐ do not know<br>☐ can not disclose</td><td>[Please tick the appropriate box:]<br>Does the tool allow for an assessment of climate targets alignment?<br>☐ Yes,<br>☐ climate risk and climate targets alignment are both reflected in the same climate risk indicator / analysis output<br>☐ climate risk and climate targets alignment are both analysed and provided as separate risk indicators / separate analysis output</td></tr>
</table>

| | |
|---|---|
| | ☐ Not yet, but extension to analyse climate targets alignment is under development, as follows: *[Please specify]*<br>☐ No,<br>☐ but following extension to assess climate targets alignment would be feasible: *[Please specify]*<br>☐ including physical risks in the analysis would be very challenging / not feasible to date<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Other aspects / further comments:<br><br>*☐ confidential information, please ask for permission if want to publish* | |

| Coverage | |
|---|---|
| Sectoral coverage<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate box(es):]*<br>☐ All economic sectors<br>☐ Specific sectors, namely:<br>☐ Coal – mining and terminals<br>☐ Oil and gas – exploration and production<br>☐ Oil and gas – refining and wholesale<br>☐ Utilities<br>☐ Manufacturing – energy intensive<br>☐ Manufacturing – automobile<br>☐ Manufacturing – other<br>☐ Agriculture, forestry, fishing<br>☐ Transportation and Logistics – surface<br>☐ Transportation and Logistics – air<br>☐ Transportation and Logistics – shipping<br>☐ Information and communication<br>☐ Real estate<br>☐ Water supply; sewerage, waste management<br>☐ Construction<br>☐ Wholesale and retail trade<br>☐ Financial services<br>☐ Other services<br>☐ Other: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Country coverage<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ World<br>☐ Country-blind<br>☐ Specific countries/regions, namely: *[Please specify]*<br>☐ Other: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Emission coverage by tool given user data | *[Please tick the appropriate boxes:]*<br>☐ Carbon Dioxide ($CO_2$); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐ |

| | |
|---|---|
| on various emissions was available<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | ☐ Methane ($CH_4$); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐<br>☐ Nitrous Oxide ($N_2O$); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐<br>☐ Ozone ($O_3$); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐<br>☐ Chlorofluorocarbons (CFCs); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐<br>☐ Hydrofluorocarbons (HCFCs, HFCs); Scope 1 ☐, Scope 2 ☐, Scope 3 ☐<br><br>☐ Sector-dependent<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Analysis time steps<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate box, if applicable:]*<br>☐ Fully flexible<br>☐ 1-year time steps<br>☐ 5-year time steps<br>☐ 10-year time steps<br>☐ Other: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Further comments:<br><br>☐ *confidential information, please ask for permission if want to publish* | |

| Transparency, accessibility and quality control | | |
|---|---|---|
| Tool usage / business model | ☐ Public, free access<br>☐ Public, paywall, fixed price<br>☐ Public, paywall, customized<br>☐ Other: *[Please specify]* | Access description: *[Please specify]*<br><br>Costs for representative analysis in [if applicable]: *[Please specify. If costs differ depending on the use case, you can provide a range from XUSD/EUR for very basic use case A to Y USD/EUR for most extensive use case B]*<br><br>Link: *[Please specify]* |
| Underlying model setup / model code | ☐ Public, free access<br>☐ Tool users only<br>☐ Private, tool owner only<br>☐ Other: *[Please specify]* | Access description: *[Please specify]*<br><br>Link model setup / model code: *[Please specify]* |
| Underlying scenario / model assumptions | ☐ Public, free access<br>☐ Tool users only<br>☐ Private, tool owner only<br>☐ Other: *[Please specify]* | Access description: *[Please specify]*<br><br>Link model assumptions description: *[Please specify]* |
| Emission data quality<br><br>☐ do not know<br>☐ can not disclose | Approach to gather emission data: *[Please tick appropriate box]*<br>☐ Estimated, by tool provider, with the following approach: *[Please specify]*<br>☐ Estimated, by third party provider: *[Please specify name]*, with the following approach: *[Please specify]*<br>☐ Self-reported, not third-party verified, using the following source: *[Please specify]*<br>☐ Self-reported, third-party verified, using the following source: *[Please specify]* | |

| | |
|---|---|
| | ☐ Other: *[Please specify]*<br><br>How do you deal with missing emission data? *[Please specify]*<br><br>How do you account for emission data accuracy uncertainty? *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| Other aspects / further comments:<br><br>☐ *confidential information, please ask for permission if want to publish* | |

# PART 2 – Economic & financial impact (approx. 30-60 minutes)

| Details tool setup – Economic impact | |
|---|---|
| **Economic losses** considered in the tool<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ Loss in profits<br>☐ Loss in revenues, via:<br>    ☐ Decrease in demand => wholesale price decrease<br>    ☐ Increase in wholesale price => decrease in demand<br>    ☐ Other: *[Please specify]*<br>☐ Increase in production costs, via:<br>    ☐ Increase in input prices<br>    ☐ Increase in production technology-related fix costs<br>    ☐ Increase in production technology-related variable costs<br>    ☐ Other: *[Please specify]*<br>☐ Other: *[Please specify]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Economic opportunities** considered in the tool<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ Increase in profits<br>☐ Increase in revenues, via:<br>    ☐ Increase in demand => wholesale price increase<br>    ☐ Lower wholesale price than competitors => increase in demand<br>    ☐ Other: *[Please specify]*<br>☐ Decrease in production costs, via:<br>    ☐ Decrease in input prices<br>    ☐ Decrease in production technology-related fix costs<br>    ☐ Decrease in production technology-related variable costs<br>    ☐ Other: *[Please specify]*<br>☐ Other: *[Please specify]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Macroeconomic environment** considered in the tool<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ Transition-induced change of within-sector competition<br>☐ Transition-induced change in economy's sectoral composition<br>☐ Transition-induced change in trade patterns<br>☐ Other: *[Please specify]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |

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| Adaptive capacity considered in the tool<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ Cost pass-through to consumers (demand price elasticity)<br>☐ Input substitution<br>☐ Capex plan adjustments<br>☐ Business model adjustment<br>☐ Credible Paris-Agreement-aligned climate strategy<br>☐ Other: *[Please specify]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Other aspects / further comments:<br><br>*☐ confidential information, please ask for permission if want to publish* | |

| Details tool setup – Financial impact | |
|---|---|
| Key financial metrics, directly provided by the tool<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>Transition-risk adjusted<br>☐ Asset price<br>☐ Expected returns<br>☐ Expected dividends<br>☐ Alpha*<br>☐ Beta*<br>☐ Climate-related additional Asset Pricing Model Factor*<br>☐ Standard deviation<br>☐ R-squared*<br>☐ Sharpe ratio*<br>☐ Sortino ratio*<br>☐ Value-at-risk<br>☐ Maximum drawdown<br><br>☐ Firm value, using the following approach: *[Please specify]*<br>☐ Cost of capital<br>☐ Value of assets in case of liquidation<br><br>☐ Probability of default<br>☐ Loss given default<br>☐ Value of collateral<br>☐ Distance-to-default (Merton model)<br>☐ Credit rating<br><br>☐ Other: *[Please specify]*<br><br>* For metrics that involve a market benchmark / risk-free assets in addition to the individual assets' adjusted value: Do you use a transition-risk adjusted benchmark / transition risk-adjusted risk-free assets as basis of comparison (in contrast to using the status quo market benchmark / status quo risk-free asset estimates)? |

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| | ☐ Yes<br>☐ No, because *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Key financial metrics, that can be directly calculated** with the tool output<br><br>☐ do not know<br>☐ can not disclose | *[Please tick the appropriate boxes:]*<br>Transition-risk adjusted<br>☐ Asset price<br>☐ Expected returns<br>☐ Expected dividends<br>☐ Alpha*<br>☐ Beta*<br>☐ Climate-related additional Asset Pricing Model Factor*<br>☐ Standard deviation<br>☐ R-squared*<br>☐ Sharpe ratio*<br>☐ Sortino ratio*<br>☐ Value-at-risk<br>☐ Maximum drawdown<br><br>☐ Firm value, using the following approach: *[Please specify]*<br>☐ Cost of capital<br>☐ Value of assets in case of liquidation<br><br>☐ Probability of default<br>☐ Loss given default<br>☐ Value of collateral<br>☐ Distance-to-default (Merton model)<br>☐ Credit rating<br><br>☐ Other: *[Please specify]*<br><br>* For metrics that involve a market benchmark / risk-free assets in addition to the individual assets' adjusted value: Does the tool also allow to calculate the transition-risk adjusted benchmark / transition risk-adjusted risk-free assets as basis of comparison (in contrast to using the status quo market benchmark / status quo risk-free asset estimates)?<br>☐ Yes<br>☐ No, because *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Amplification mechanisms considered** that intensify the impact of the initial shock<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes:]*<br>☐ None<br>☐ Network effects<br>☐ Revision of investor expectations / sentiment<br>☐ Balance sheet effects<br>☐ Other, namely *[Please specify]* |

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| | ☐ *confidential information, please ask for permission if want to publish* |
| Other aspects / further comments:<br><br>☐ *confidential information, please ask for permission if want to publish* | |

# PART 3 – Tool drivers (approx. 30-60 minutes)

| Details tool drivers – Specifications of climate-related developments & events | |
|---|---|
| Scenario output / qualitative information used by tool<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick the appropriate boxes / specify, which scenario output or qualitative reasoning information is actually used for the economic and financial analysis of the tool]*<br>☐ Carbon price (uniform)<br>☐ Carbon price (differentiated by sector)<br>☐ Emission limits / constraints / budgets (by sector)<br>☐ Emission limits / constraints / budgets (by country)<br>☐ Technology deployment<br>☐ Change in demand patterns<br>☐ Overall economic growth<br>☐ Sectoral composition of economy<br>☐ International trade patterns<br>☐ Other: *[Please specify]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Model approach<br><br>☐ do not know<br>☐ can not disclose | *[Please tick appropriate box:]*<br>☐ Top-down, starting point of analysis: *[Please specify]*<br>☐ Bottom-up, starting point of analysis: *[Please specify]*<br>☐ Other: *[Please specify, e.g. if you use a combination of both]*<br><br>☐ Sector-dependent<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Impact on unit of interest<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | Approach to determine impact on specific unit of interest: *[Please specify, e.g. cost-efficient allocation based on model-derived carbon price to achieve the temperature limit, or else]*<br><br>Differentiation within units of interest: *[Please specify if differentiation by unit of interest is possible, e.g. by modelling different policies for different sectors, trade-offs between different sectoral abatements, or else]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| a) **Qualitative reasoning** employed by the tool<br><br>☐ not applicable | |

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| **Key assumptions and information used** to specify baseline and transition considerations<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[If you use qualitative reasoning instead of scenario output, please specify key assumptions and the source of information used by the tool to specify baseline and transition considerations that feed into the economic and financial analysis]*<br><br>☐ Sector-dependent: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Temperature limit** transition considerations<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick appropriate boxes:]*<br>☐ 1.5°C<br>☐ below 2°C<br>☐ 2°C<br>☐ > 2°C - 3°C<br>☐ > 3°C - 4°C<br>☐ > 4°C<br>☐ Other: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| b) **Baseline scenarios** employed by the tool<br><br>☐ not applicable | |
| **Name and provider** reference scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick appropriate box and specify:]*<br>☐ Single default reference scenario: *[Please specify name],* Provider: *[Please specify]*<br>☐ Range of default reference scenarios to choose from: *[Please specify name],* Provider: *[Please specify]*<br>☐ Reference scenario-neutral, with the following limitations/ data requirements: *[Please specify]*<br><br>☐ Sector-dependent: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Key drivers and assumptions** reference scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please specify]*<br><br>☐ Sector-dependent: *[Please specify]*<br><br>☐ *confidential information, please ask for permission if want to publish* |
| **Temperature impact** reference scenarios<br><br>☐ do not know<br>☐ can not disclose | *[Please tick appropriate box(es):]*<br>☐ 1.5°C<br>☐ below 2°C<br>☐ 2°C<br>☐ > 2°C - 3°C |

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| ☐ user-specific | ☐ > 3°C - 4°C<br>☐ > 4°C<br>☐ Other: *[Please specify]*<br><br>Likelihood of temperature impact: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| c) **Transition scenarios** employed by the tool<br><br>☐ not applicable | |
| **Name and provider** transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick appropriate box and specify:]*<br>☐ Single default transition scenario: *[Please specify name],* Provider: *[Please specify]*<br>☐ Range of default transition scenarios to choose from: *[Please specify names],* Provider: *[Please specify]*<br>☐ Transition scenario-neutral, with the following limitations/ data requirements: *[Please specify]*<br><br>☐ Sector-dependent: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Key drivers and assumptions** transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please specify]*<br><br>☐ Sector-dependent: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Temperature limit** transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | *[Please tick appropriate boxes:]*<br>☐ 1.5°C<br>☐ below 2°C<br>☐ 2°C<br>☐ > 2°C - 3°C<br>☐ > 3°C - 4°C<br>☐ > 4°C<br>☐ Other: *[Please specify]*<br><br>Likelihood to stay within the temperature limit: *[Please specify]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Emission trajectory** in transition scenarios<br><br>☐ do not know<br>☐ can not disclose | Emission peak in year: *[Please specify]*<br>Net-zero emissions in year: *[Please specify default]*<br>Full decarbonisation in year: *[Please specify default]*<br><br>☐ Sector-dependent: *[Please specify]* |

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| ☐ user-specific | *☐ confidential information, please ask for permission if want to publish* |
| **Overshoot** in transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | Emission overshoot?<br>☐ Yes<br>☐ No<br>☐ Sector-dependent: *[Please specify]*<br><br>Temperature overshoot?<br>☐ Yes<br>☐ No<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Role of CCS** in transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | CCS technologies considered: *[Please specify]*<br><br>Assumptions on trajectory of CCS deployment required to stay within temperature target: *[Please specify, e.g. scale up of technology AAA by XX% until year YY, compared with status quo]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| **Energy mix in 2040** in transition scenarios<br><br>☐ do not know<br>☐ can not disclose<br><br>☐ user-specific | Share of renewable energies in energy mix: *[Please specify default %]*<br><br>Share of natural gas in energy mix of target year: *[Please specify default %]*<br><br>Share of oil in energy mix of target year: *[Please specify default %]*<br><br>Share of coal in energy mix of target year: *[Please specify default %]*<br><br>*☐ confidential information, please ask for permission if want to publish* |
| Further comments:<br><br>*☐ confidential information, please ask for permission if want to publish* | |

## Thank you very much!

## Your answers are very highly appreciated.

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