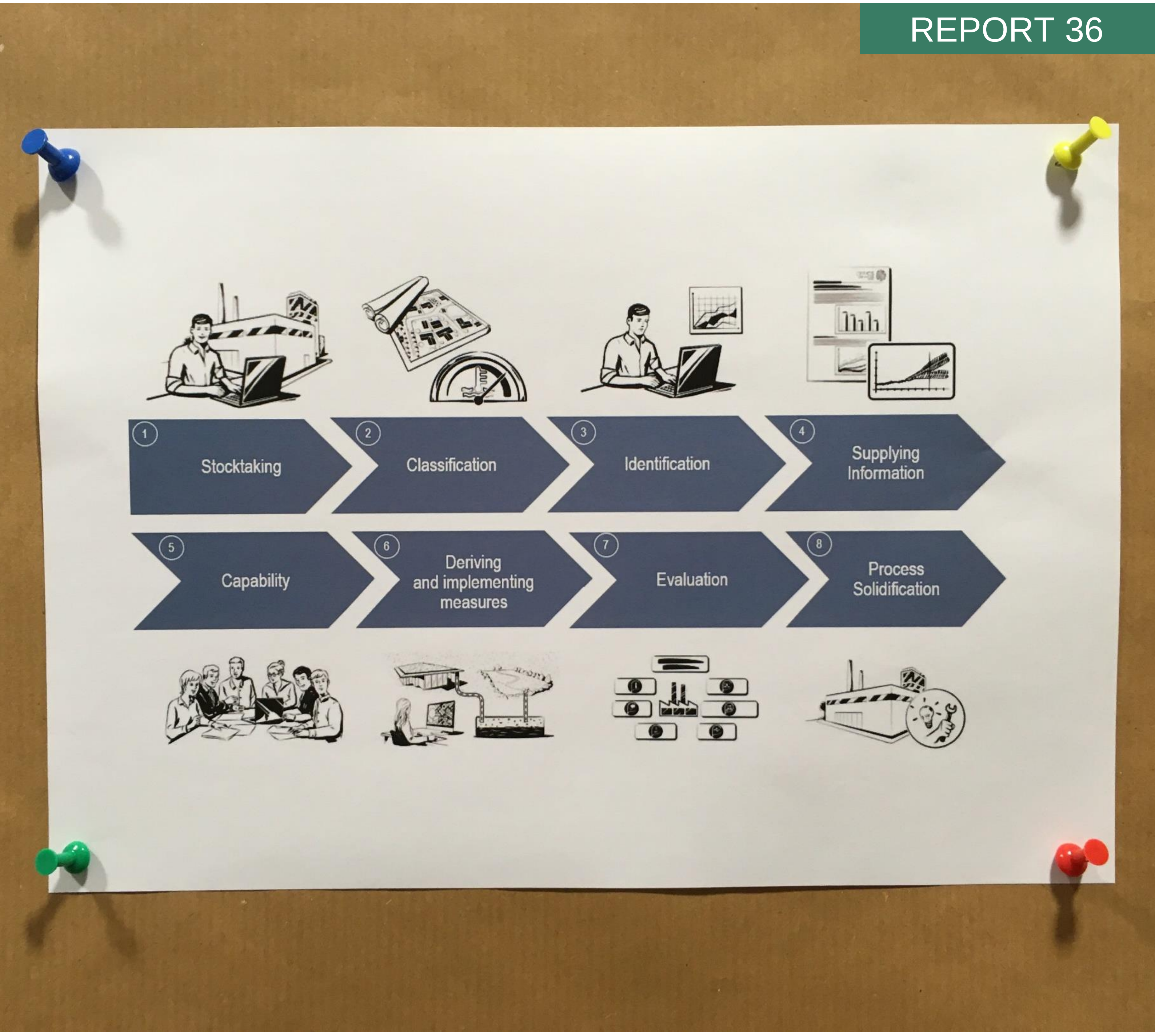
Climate Service Center Germany

A Process Model for Integrating Future-Oriented Climate Information into Business Establishments

REPORT 36



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REPORT 36

A Process Model for Integrating Future-Oriented Climate Change Information into Business Establishments

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Climate Service Center Germany (GERICS)

March 2024 (in English: December 2024)

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Notice to readers for quick navigation:

After a theoretical derivation and scientific-theoretical classification (Chapter 2) and the derivation of the state of knowledge and identifying the need for research (Chapter 3), Chapter 4 describes the individual phases of the GERICS Process model for Integrating Future-Oriented Climate Change Information into Business Establishments. Text passages relating to the **EU Taxonomy Regulation** can be found both in Chapter 3.1 (explanation of the new requirements in the context of the EU framework for sustainable finance) and in Chapter 4 in the respective **phases of the Process model** on pages 5, 10-15, 17, 19-20, 25, 29, 32-34, 42, 45-46.

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1. Introduction

This report shows how the following are linked: insufficiently considering long-term challenges posed by climate change in corporate activities, new requirements for financial and sustainability-related reporting based on EU-level regulations, and integrating climate change information into risk management.

The focus lies on introducing the GERICS Process model for Integrating Future-Oriented Climate Change Information along the phases of a risk management process while incorporating prototypical GERICS products. The intention in this context is to close the identified gap in adaptation processes at the transition from problem identification to the derivation of measures.

The aim is to enable decision-makers at business establishments to independently determine their own climate change-related susceptibilities and to evaluate them, taking into account both climate change information and local information. Building on this, companies can identify suitable adaptation options to avoid or at least mitigate potential damages caused by extreme weather events and other climatic changes. The approach was developed to close an existing gap, as business decision-makers, for the most part, do not currently possess the suitable methods and skills to integrate climate change information into corresponding adaptation strategies and measures (Attoh et al. 2022; Loew et al. 2021; Hurrelmann et al. 2018).

Climate change and its regional impacts are already being felt in Germany (IPCC 2023a; 2022a; 2021; 2018; Jacob et al. 2021; Kahlenborn et al. 2021; UBA 2019). The average near-surface air temperature has already increased considerably between 1881 and today, with temperatures in Germany rising more rapidly than the global average (IPCC 2021; Kaspar et al. 2020).

Furthermore, changes in precipitation regimes can be observed in many regions in Germany. There is a particular increase in the amount of precipitation in winter, which also occurs less frequently as snow. Additionally, the summers are drier. (Deutschländer and Mächel 2017; DWD 2017) One consequence of climate change is also the increase in heavy rain events, which can already be seen regionally (Papalexiou and Montanari 2019; Fischer and Knutti 2016; Westra et al. 2014). A particularly large number of these events occurred in 2018, which was also characterized by long periods of very low precipitation and high evaporation rates caused by high temperatures (Jacob et al. 2021). The increase in heavy rainfall events is due to the physical effect that higher air temperatures allow the atmosphere to absorb more water vapor, which can cause convective precipitation to intensify. In addition, the number of consecutive dry days is expected to increase in summer and a trend towards more intensive rainfall events is anticipated (Giorgi et al. 2019; Giorgi et al. 2011).

The consequences of climate change are also associated with extensive economic impacts such as damage costs, whereby a large proportion of the damage can be attributed to extreme weather events. Such incidences include excessive heat, drought, floods or heavy rainfall events that lead, for example, to infrastructural damage, rising health costs or crop failures (Trenczek et al. 2022a; Trenczek et al. 2022b). Flooding, in particular, caused by rivers overflowing, heavy rainfall and flash floods have been the costliest extreme weather events in

Germany to date. In addition to destruction of buildings and transport infrastructure, industry and commerce have also been affected by flooded production halls or disrupted supply chains. This has altogether resulted in more than 70 billion euros in damage since the year 2000 (Trenczek et al. 2022a; Trenczek et al. 2022c).

A rise in thermal stress is also becoming increasingly more important as a result. In general, the impacts of increasing heat vary depending on how vulnerable affected people, neighborhoods, sites, municipalities or regions are. For example, older people, children, groups with low socio-economic status and individuals with health problems tend to be more vulnerable to the impacts of climate change than the general population (GERICS 2020). The health of those with certain illnesses (e.g. cardiovascular and respiratory diseases or diabetes) is also more affected by heat, which is often associated with a higher risk of heat-related death (European Climate and Health Observatory 2022; European Environmental Agency [EEA] 2018a).

Overall, the negative effects of heat on human well-being and health are clearly documented (GERICS 2020; Hanefeld et al. 2019; Muthers et al. 2017), whereby very warm nights, in particular, can lead to the body’s inability to regenerate properly, thereby increasing the general risk of illness. Heat has therefore not only been proven to lead to decreased labor productivity, but also to additional - and sometimes serious - economic consequences, resulting in associated costs that often develop only slowly and are frequently not highly discernable. In summary, heat events are responsible for approximately 99 percent of at least 30,000 extreme weather-related deaths in Germany since the year 2000 (Trenczek et al. 2022a; Trenczek et al. 2022b).

Against the backdrop of these and other expected future climate change impacts, it becomes evident that in the future there must be - for businesses as well - a much greater focus on joint consideration of climate protection, climate change mitigation and sustainability (Jacob et al. 2021).

On the one hand, the financial and economic system must be fundamentally restructured in order to meet the first Paris Agreement target. This means ensuring that the potential increase in global average temperature remains well below the 2°C pathway and that efforts will continue towards limiting the temperature increase to a maximum of 1.5°C above pre-industrial levels (Paris Agreement 2015, Art. 2.1.(a)). On the other hand, the financial and economic system must become resilient to climate-related physical, market, regulatory and liability risks with the aim of maintaining financial stability and increase macroeconomic climate resilience (Paris Agreement 2015, Art. 2.1 (b)). In order to achieve both goals, financial streams must be “consistent with a pathway towards low greenhouse gas emissions and climate-resilient development” (Paris Agreement 2015, Art. 2.1 (c)). This is the third goal of the Paris Agreement.

Against this backdrop, it is of crucial importance to overcome the “tragedy of the horizon” already described by Mark Carney in 2015. This refers to the “catastrophic impacts of climate change will be felt beyond the traditional horizons of most [financial] actors – imposing a cost on future generations that the current generation has no direct incentive to fix” (Carney 2015, 3). It is to be expected in this context that a policy framework that is defined at an early stage and offers planning certainty would enable the necessary asset adjustment without disrupting the financial system or imposing negative consequences on the system that could be caused by a late and abrupt transition to a climate protection pathway well below the 2° C (Gianfrate 2018). For a stable transition to a low carbon financial and economic system and to prepare for climate-related risks, business establishments must above all take reasonable measures to mitigate and manage risks (Mahammadzadeh 2011; Kolk et al. 2008). Comparable, clear and forward-oriented disclosure of climate-related financial data is key in recognizing, assessing and responding appropriately to climate-related impacts (Carney 2018).

Businesses are also faced with increasing requirements for non-financial reporting - for example, to consider climate change scenarios within risk analysis and to provide evidence of substantial contributions of economic activities to the environmental objectives pertaining to the EU Taxonomy Regulation (Attoh et al. 2022; Bals et al. 2022; Europäisches Parlament und Rat der Europäischen Union 2020; TCFD 2017).

Currently, however, companies still remain focused on disclosing past - and monitoring current - emissions of CO_2. This means that fundamental deficits are still evident in considering future-oriented climate data and scenarios in reporting as well as in scenario-based consideration of long-term planning periods (Attoh et al. 2022; Lessmann/Schütze 2022; Schütze 2022; Loew et al. 2021; Hurrelmann et al. 2018; Freimann et al. 2014). In addition to climate protection, it is therefore becoming increasingly important to take a look at possible future climate changes along with their opportunities and risks in a scientifically sound way. Furthermore, analysis methods must be developed in order to combine these aspects with local information, such as information on processes within companies, previous impacts and the criticality of potentially affected elements for achieving business goals. In addition, they need to be integrated into risk management, strategic orientation and business reporting (TCFD 2017; Mahammadzadeh 2011).

This report therefore describes and discusses an innovative approach for integrating climate change information into business processes, an approach that was developed in collaboration with business establishments.

The report is structured as follows: Chapter 2 outlines the relevance of widely existing business preferences on a short-term as well as the importance of transparent information for entrepreneurial behavior from the perspective of scientific theory. The current need for research and action to integrate climate change information and climate scenarios into business processes and reporting is outlined in Chapter 3. Chapter 4 presents a novel process model for practical integration of climate change information into business processes ("*GERICS Process model for Integrating Future-Oriented Climate Change Information in Business Establishments"*, from here on referred to as the "GERICS Process model") based on its eight phases. Chapter 5 concludes the report with a summary.

2. The Relevance of Current Business Preferences and Transparent Information

In summary, the goals of the market in general are characterized, for example, by Chichilnisky (2016), as “short-term oriented”. Based on the classical market economic theory, he refers to Koopmans' concept of impatience as an explanation, in the sense of a prerequisite of the Arrow-Debreu market theory. The theory explains that money loses value over time due to the discounting of utility (Anchugina 2017; Chichilnisky 2016; Bleichrodt et al. 2008). In the process, what is made evident is the conflict between short-term market goals and future-oriented requirements for sustainable development as well as the needs of future generations and intergenerational justice issues (Chichilnisky 2016).

These aspects of intergenerational externalities or intertemporal externalities were first discussed in depth by Pigou as early as 1912 in his seminal work “Wealth and Welfare” (Pigou 1912. Such aspects are still relevant today (Edenhofer et al. 2021; Groth and Baumgärtner 2009). Pigou argues that people have a strong preference for the present, which means preferring a short-term benefit to an equally high future benefit - especially if the future benefit does not accrue to themselves but to future generations. As a result of this preference, people often make short-term decisions that are detrimental to themselves and even more so to future generations. These are mainly decisions on the use and development of capital stocks. In addition to the underinvestment in developing permanent human-made capital stocks, the short-term preference for the present also results in an excessive depletion of natural capital stocks. Using the example of long-term initiatives such as reforestation and measures to improve water supply, Pigou points out emphatically that current generations exploit natural resources in a wasteful manner so that resources are not available for use by future generations. This problem of intergenerational externalities therefore lies in the fact that the current generation imposes costs on future generations in the form of limited or no longer existing opportunities to utilize resources. Pigou considers this preference for the present, which was already described by Sidgwick (1891), to be irrational and ethically unjustifiable. The state - understood paternalistically - should therefore not allow intergenerational injustices and welfare losses to arise due to such preferences. According to Pigou, the intergenerational justice and efficiency problems caused by the human preference for the present cannot be overcome by capital markets that reward waiting. Pigou reasons that the long-term lack of substitutability of goods as well as uncertain individual life expectancy prevent the implementation of a measure that only pays off in the long term (Pigou 1921).

The crucial importance of these intergenerational aspects was also highlighted a full one hundred years later through the verdict handed down by the German Federal Constitutional Court in 2021 in the wake of constitutional complaints against the Climate Protection Act (Bundesverfassungsgericht 2021). The ruling emphasized that fundamental rights were substantially reduced by permitted emission levels at the time, which would significantly reduce the remaining emission options after 2030 and thereby endanger virtually all freedoms protected by fundamental rights. As an intertemporal safeguard of freedom, fundamental rights protect the complainants here from a comprehensive threat to their freedom by unilaterally shifting the burden of greenhouse gas reduction imposed by Article 20a GG into the future.

The legislator should therefore have taken precautions to ensure that a transition to climate neutrality included the preservation of freedoms.

Carney (2018; 2016; 2015) addresses the conflict between short and long-term planning horizons in relation to business enterprises and links them to the central sustainability challenge of climate change. He argues that the catastrophic impacts of climate change will be felt beyond the traditional planning horizons of most stakeholders, imposing costs on future generations that the current generation has no direct incentive to address: “climate change is the Tragedy of the Horizon” (2015, 3). Carney argues that the time horizon of financial and corporate stakeholders is too short to successfully address or adequately consider the climate change problem, as the effects will mainly be experienced in the future. If, however, the effects of climate change impact financial stability, the risk may increase that the Paris Agreement targets will be even more difficult - or impossible - to achieve. As these risks in turn depend on cumulative emissions, early countermeasures in the sense of ambitious climate protection make it possible to reduce future damage and costs of adaptation measures (Klepper et al. 2017; Carney 2015). Carney therefore suggests a rapid but smooth transition to a low-carbon financial system (Carney 2016). He points out that transparent and credible information is crucial here so that market participants can assess climate-related financial risks and opportunities as well as prepare and respond accordingly (Carney 2016).

Carney therefore calls for the disclosure of future-oriented, qualitative and quantitative information that enables investors to assess how climate-related factors could affect the companies. Furthermore, the robustness of the business strategy should be evaluated through regular scenario analyses (Carney 2016). This can surmount the “Tragedy of the Horizon” and pave the way for the transition to a low-carbon financial system. (Carney 2018; 2016; 2015; EU High-level Expert Group on Sustainable Finance [HLEG] 2018; TCFD 2017; CDP 2017; Weber 2018). In economic theory, the importance of transparent information is emphasized by the condition of complete information as one of the five key conditions for a functioning market system (Fernández-Olit et al. 2018; Common and Stagl 2005).

Information asymmetry arises, for example, when the borrower does not provide the lender with all the information he or she possesses about the company or products so that the borrower gains an advantage over the lender (Frank and Cartwright 2013). This can lead to serious principal-agent problems in financial markets. First, adverse selection can occur, which means that different borrowers have different probabilities for repaying the loan. In order to identify reliable borrowers, the lender must therefore utilize various screening instruments (Stiglitz and Weiss 1981). Secondly, moral hazard behavior can occur where borrowers are incentivized to take greater risks because the cost of that risk is borne by others (Frank and Cartwright 2013). These problems concerning information can lead to credit rationing and exclusion from the financial market (Stiglitz and Weiss 1981).

In regard to the risks and opportunities associated with climate change, the principal-agent problems outlined above, combined with misaligned incentives, can lead to the actor's long-term horizon at the end of the investment chain not being taken into account by financial intermediaries and that the focus lies in short-term price development. This can therefore lead to deficits on both sides of the investment chain, as the climate-related risk of an investment - particularly a long-term one - is insufficiently taken into account on either side (HLEG 2018).

As a consequence, the information asymmetry becomes an information deficit if neither the lenders nor the borrowers adequately consider or assess the climate-related risks and opportunities of an investment. Sustainable and long-term investment decisions therefore require transparency in regard to long-term climate related risks and opportunities (Bals et al. 2022; Europäisches Parlament und Rat der Europäischen Union 2020; HLEG 2018; Carney 2018; 2016; 2015; CDP 2017; TCFD 2017). The value of the corresponding information gain can therefore also be a gain for both businesses and investors: businesses can better understand their risks and opportunities and utilize this knowledge as a foundation for strategic decisions. Investors can, in turn, use the disclosed information to identify companies that are aware of the potential impacts of climate change and adjust their investment portfolios accordingly.

3. Integrating Climate Change Information: Need for Research and Action

3.1. State of knowledge and practical implementation

Research has so far focused on categorizing business strategies in the context of climate change and on identifying drivers and barriers to integrate climate-related aspects into strategic considerations (Hurrelmann et al. 2018). For future-oriented reporting on climate-related factors, a distinction is made between physical risks and transitory risks. Physical risks include the direct acute impacts of climate change that are caused by extreme weather events and chronic, slow-onset changes and trends (UNDRR 2022; Loew et al. 2021). In contrast, transition risks affect companies as part of the necessary transition to a low-carbon and climate-resilient economy - for example, through new legal regulations on energy efficiency or altered customer demands for climate-friendly products and services at market level (TCFD 2017; Europäische Kommission 2019; Loew et al. 2021) (**Figure 1**; for a supplementary explanation see also **Appendix A**).

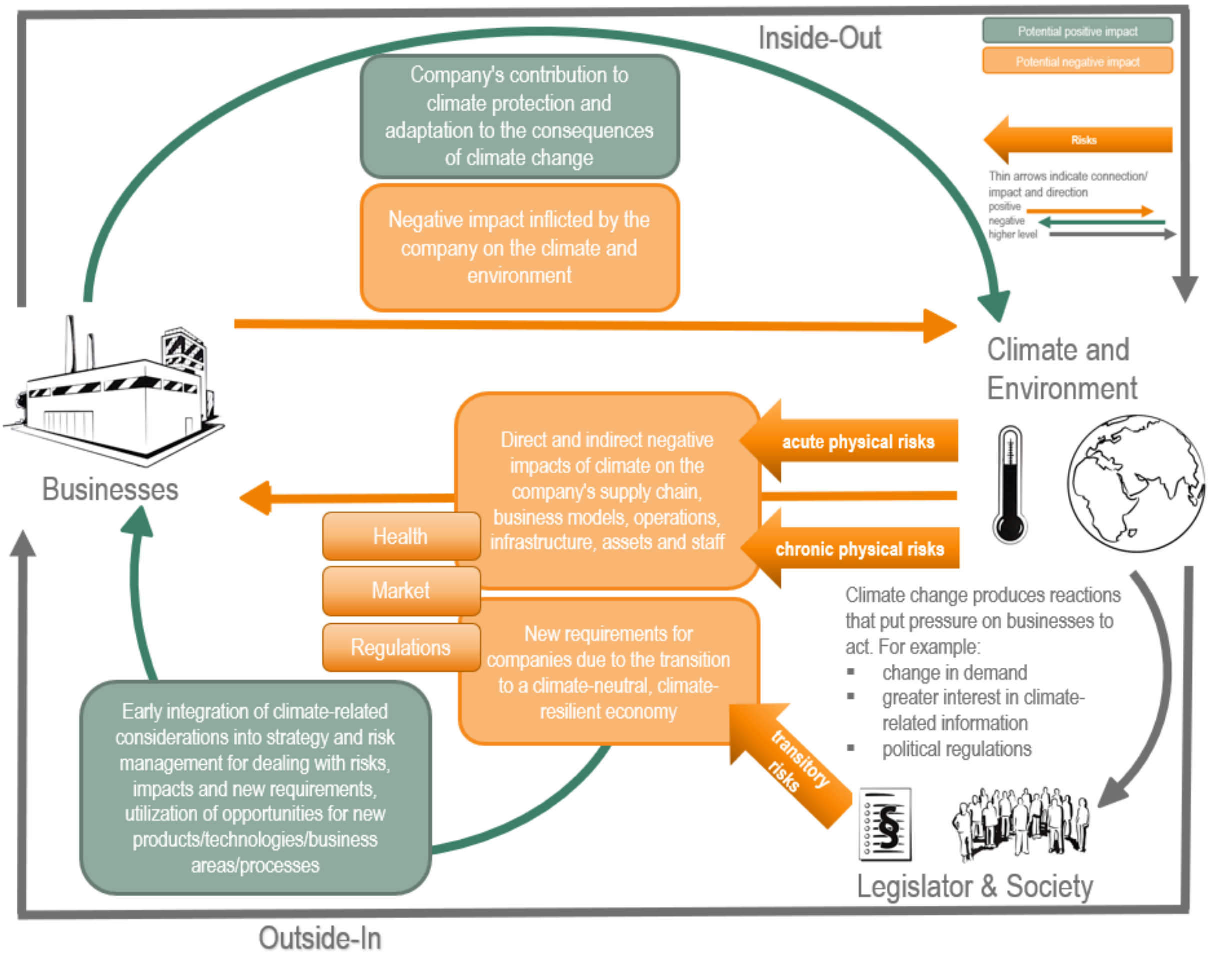

Figure 1 Climate change interactions, opportunities and risks for businesses (in-house visualization based on Loew et al. 2021; Europäische Kommission 2019 and TCFD 2017).

In 2021, Loew et al. examined the extent to which climate-related risks are already included in business reporting and the extent to which the associated information is disclosed. Analysis of the reports shows that businesses perceive that they are more likely to be affected by transition risks than physical risks arising from climate change (Loew et al. 2021). The potential financial impacts of transition risks and their probability of occurrence are estimated to be higher overall than the corresponding impacts of physical climate change effects. According to the authors' assessment, this is because “physical climate risks often only materialize in a medium or long-term time frame”[1] (Loew et al. 2021, p. 60) and physical impacts are “more difficult to grasp and not easily predictable” (Loew et al. 2021, p. 116). Likewise, Klepper et al. (2017) evaluated surveys on the subjective assessment of climate change impact, in which the businesses surveyed attributed greater importance to the indirect consequences than to the direct physical consequences. The greatest challenges were seen in the areas of logistics, investment and financing.

An additional reason cited for the perceived higher level of concern from transition risks is that physical risks have so far had a low to balanced status compared to transition risks in political processes and reporting guidelines (Loew et al. 2021). This imbalance is addressed by the new requirements for analyzing and considering climate-related risks in reporting from recommendations on behalf of the following: the Task Force on Climate-Related Financial Disclosures (TCFD 2017); the EU Taxonomy Regulation (Europäisches Parlament und Rat der Europäischen Union 2020) and the Corporate Sustainability Reporting Directive (CSRD) (Europäisches Parlament und Rat der Europäischen Union 2022). They are intended to help raise awareness in the business sector regarding potential physical risks as well.

Under the framework of the European Green Deal, the EU Taxonomy should be seen as part of a larger context for sustainable EU finances (European Union 2023a; 2023b; see also **Figure 2** below).

[1] Translated to English from the originally German source

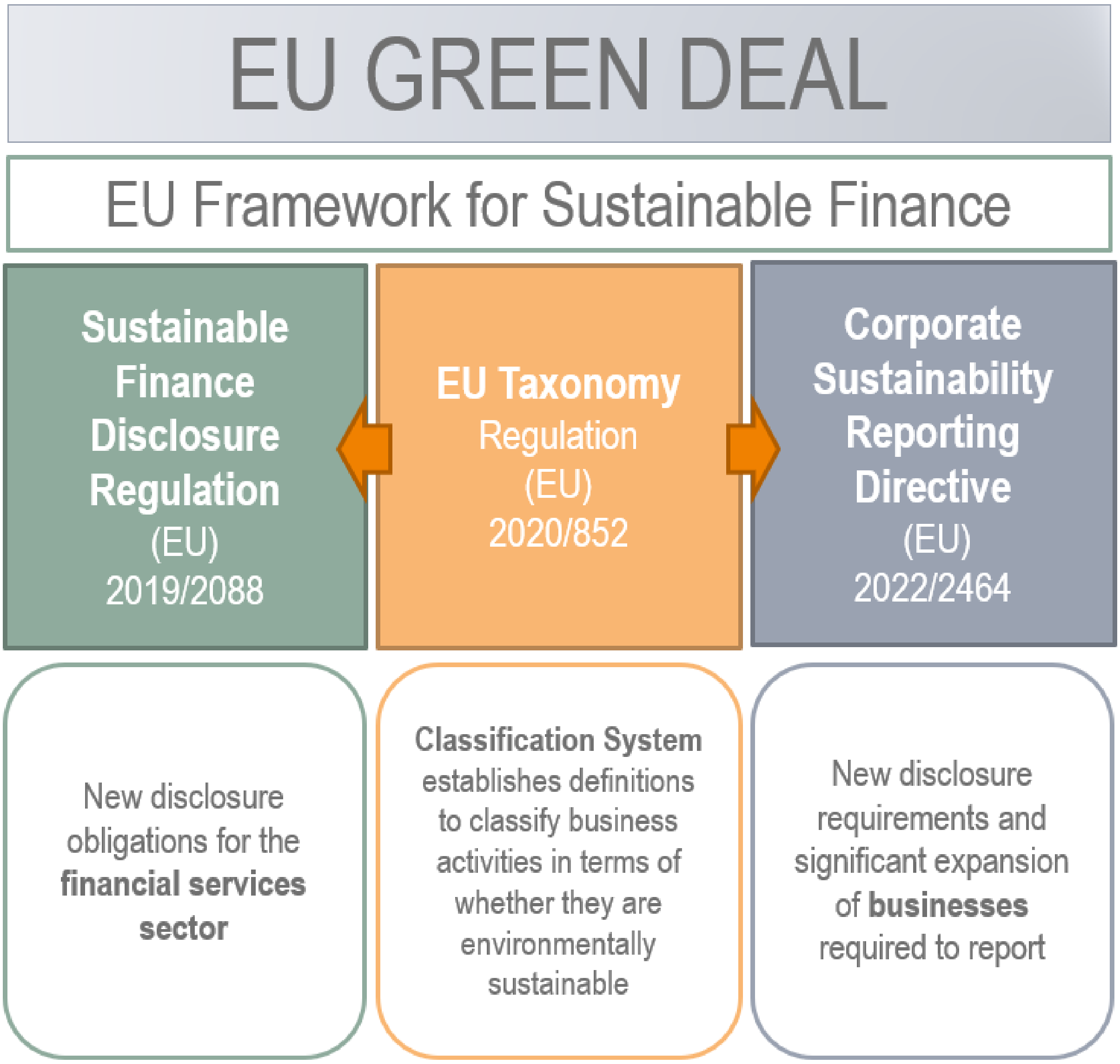

Figure 2 The EU Taxonomy within the EU framework for sustainable finance (in-house visualisation based on the European Union 2023a; 2023b).

While the Sustainable Finance Disclosure Regulation (SFDR) regulates disclosure requirements for the financial services sector, the Corporate Sustainability Reporting Directive (CSRD) stipulates disclosure obligations for businesses regarding sustainability information. To ensure that everyone can rely on uniform definitions, the EU Taxonomy Regulation establishes a classification system for categorizing environmentally sustainable economic activities and itself contains disclosure requirements for businesses and financial market participants (European Union 2023b). It therefore acts as a link between the two.

Furthermore, the Corporate Sustainability Reporting Directive (CSRD) explicitly highlights the importance of *double materiality*. This is understood to mean taking two observational perspectives into account. On the one hand, this includes the impacts that the company itself has on the environment and the climate through its activities, but on the other, also the impacts and potential impacts that a change in climate, the environment and other sustainability aspects can have on the company and that are to be classified as material (European

Parliament and Council of the European Union 2022). Täger (2021) describes this expansion of scope, or differentiating the levels that are taken into consideration, as follows:

"It is not just climate-related impacts on the company that can be material but also impacts of a company on the climate—or any other dimension of sustainability." Double materiality is illustrated in **Figure 3**.

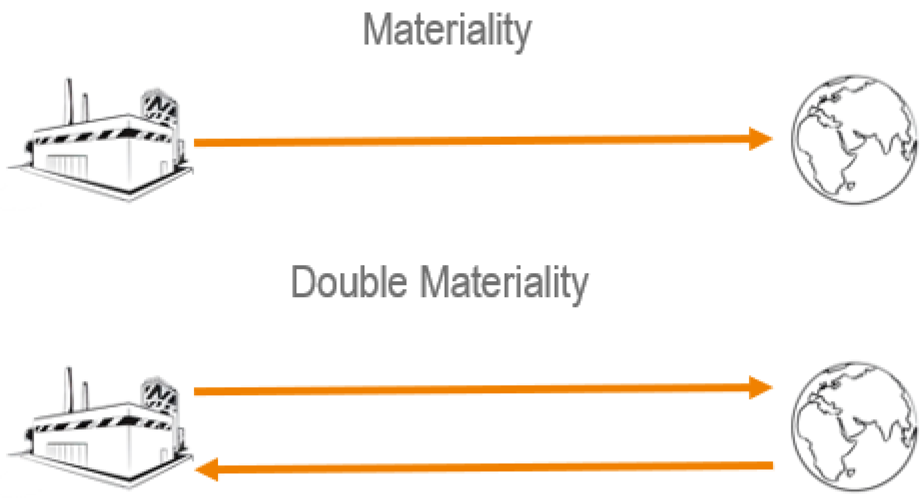

Figure 3 Concept of double materiality
(in-house visualization based on Europäisches Parlament und Rat der Europäischen Union 2022; Täger 2021).

Due to this perspective, in addition to considering the environmental impact and CO_2 emissions stemming from the company's activities, the focus also shifts to information and risk analyses that demonstrate how the company may be affected by climate impacts and the transition to a climate-neutral economy.

The CSRD closes existing gaps in the previous Non-Financial Reporting Directive (NFRD) and promotes standardization and therefore comparability in reporting. By expanding the scope of application for businesses through the CSRD, approximately 50,000 EU companies will in the future be affected by the expanded reporting obligations in regard to the quality and scope of the information to be disclosed and by the broadening of the perspective to include double materiality (European Union 2023b). The CSRD's introduction already confirms a significant increase in demand for sustainability-related information. This is attributed to the changing nature of risks - particularly climate-related risks - for businesses and the investors' increasing awareness regarding the financial impact of these risks (Europäisches Parlament und Rat der Europäischen Union 2022). For example, disclosing information on physical and transition risks and resilience, as well as plans for how a business intends to adapt to different future climate change scenarios, is especially of interest to users of this information (Europäisches Parlament und Rat der Europäischen Union 2022).

The EU Taxonomy Regulation represents a classification system that is valid for the EU framework to:

a) on the one hand, provide clarity for businesses and financial market participants as to which activities are considered "environmentally sustainable"

b) and on the other, to enable investors to recognize and invest in sustainable investments.

The EU Taxonomy is therefore to enable channeling capital flows into sustainable activities and encourage businesses to initiate new projects or expand existing ones (European Union 2023b). It is also to ensure that transforming the European economy is supported and that the goals of the European Green Deal are achieved. To this end, it contains six environmental objectives[2] (one of which is adaptation to climate change impacts, see **Figure 4**) and four related requirements for business activities to be recognized as sustainable in accordance with the EU Taxonomy (European Union 2023b; Europäisches Parlament und Rat der Europäischen Union 2020). According to Article 3 of the EU Taxonomy Regulation, these must:

- substantially contribute to at least one of the six environmental objectives under Article 9 of the EU Taxonomy Regulation
- do no significant harm to the other environmental objectives
- comply with certain minimum safeguards with regard to human rights and labor law
- comply with the specified technical screening criteria (European Union 2023b; European Parliament and Council of the European Union2020)

The Delegated Acts to the EU Taxonomy Regulation specify additional technical screening criteria for the six environmental objectives (the Climate Delegated Act specifies the first two environmental objectives - climate change mitigation and climate change adaptation - and the Environmental Delegated Act[3], which came into force on January 1st of 2024, specifies the other four environmental objectives) (European Union 2023a; Europäische Kommission 2021a). These acts define when an economic activity makes a substantial contribution to the respective environmental objective and which requirements exist for demonstrating no significant harm is done to the other environmental objectives. The screening criteria of the Climate Delegated Act so far encompass sectors with economic activities that are responsible for the majority of direct CO_2 emissions in Europe. (Europäische Kommission 2021b).

[2] These are: the environmental goals of climate change mitigation, climate change adaptation, the sustainable use and protection of water and marine resources, the transition to a circular economy, pollution prevention and control and thethe protection and restoration of biodiversity and ecosystems.

[3] https://finance.ec.europa.eu/regulation-and-supervision/financial-services-legislation/implementing-and-delegated-acts/taxonomy-regulation_en

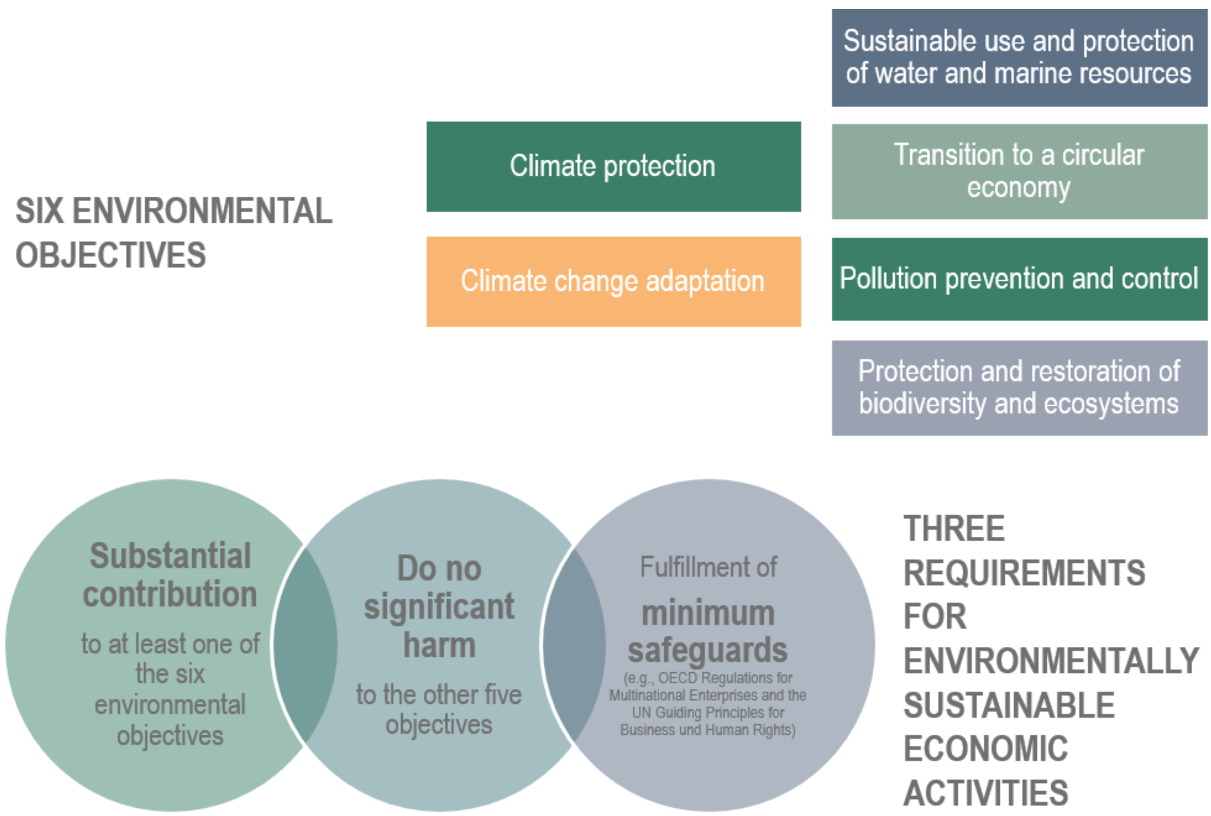

Figure 4 An overview of the six environmental objectives of the EU Taxonomy Regulation and the requirements for sustainable economic activities. (In-house visualization based on the European Parliament and Council of the European Union 2020).

To demonstrate that an activity 1) makes a substantial contribution to reducing the negative impacts of climate change or 2) causes no significant harm to the goal of climate change adaptation, a climate risk and vulnerability assessment of the expected climate impacts must be conducted using appropriate climate information. This assessment is to be carried out in accordance with the general criteria in Appendix A of Annexes I and II of the Delegated that accompanies the EU Taxonomy Regulation (Europäische Kommission 2021a). It should be carried out for economic activities based on a robust analysis of available climate data and projections across a range of future scenarios (Europäisches Parlament und Rat der Europäischen Union; TEG 2020b). Appendix A of Annexes I and II of the Delegated Regulation that accompanies the EU Taxonomy Regulations contains the following requirement: “The climate projections and assessment of impacts are based on best practice and available guidance and take into account the state-of-the-art science for vulnerability and risk analysis and related methodologies (…)” (European Commission 2021).

Regarding the climate projections to be used, the GERICS Process model in Chapter 4 utilizing the GERICS Climate outlook at county level describes (from the authors' point of view) a possible way to meet the requirement in the Delegated Regulation that accompanies the EU Taxonomy Regulation for an assessment. It uses the highest-resolution and state-of-the-art climate projections for the existing set of future scenarios with the climate scenarios. The proposed approach addresses the scenarios specified in the regulation’s footnote

(Europäische Kommission 2021a).[4] The GERICS Process model is also based on the requirement that climate change information must meet the quality criteria of i) transparency, ii) relevance/completeness iii) current state of scientific knowledge and iv) robustness (Rechid et al. 2020, unpublished assessment tool on the quality of climate change information from project work with KfW Entwicklungsbank). With regard to climate change information, this especially means:

1. Disclosure of all data used and documentation in all procedural steps as to which database was utilized and why.

2. Whether all relevant data, methods, tools and information that are available and suitable are taken into account and whether their geographic and temporal scope is appropriate.

3. Against the backdrop of further developing scientific knowledge, whether the data used corresponds to the current state of knowledge—that is, whether the data are state-of-the-art in terms of topicality, methodological approach and take into consideration existing knowledge. For climate change information, this means that existing climate assessments and reports (the *IPCC Assessment Report* at the international level, but also country-specific reports) and available climate projections based on existing emission scenarios are taken into account.

4. Climate projections always contain uncertainties due to the following: the time horizon extending far into the future; uncertain occurrence of the earlier assumptions made regarding future socio-economic developments and the associated development of emissions; modeling uncertainties; and uncertainties due to natural climate variability. There are therefore possible sources of error in the results from the assumptions, in the climate system's unpredictable processes and interrelationships as well as in the model as a simplified representation of reality. It is therefore important to be prepared for the spectrum of all plausible climate developments within which actual developments may occur. This can be taken into account by using data from different climate models of a coordinated climate simulation ensemble for different emission scenarios.

According to the requirements of the Delegated Act associated with the EU Taxonomy Regulation, existing methodologies and available guidance should also be used for the risk analysis. These include amongst others the DIN ISO-Norm 14091 "Adaptation to Climate Change – Guidelines on Vulnerability, Impacts and Risk Management" and DIN ISO-31000:2018-10 "Risk Management – Guidelines", which are referred to below.

With DIN ISO-Norm 14091, guidelines were developed in 2021 that specify a standardized procedure for vulnerability analysis and for assessing the risks associated with climate change

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3 "The future scenarios include the representative concentration pathways RCP2.6, RCP4.5, RCP6.0 and RCP8.5 used by the Intergovernmental Panel on Climate Change" (European Commission 2021a). More detailed information on using RCPs can be found in the EU Commission's DRAFT COMMISSION NOTICE dated December 19, 2022 in questions 167-169: https://ec.europa.eu/finance/docs/law/221219-draft-commission-notice-eu-taxonomy-climate.pdf

impacts. They also provide for their integration as a component in existing risk and environmental management systems (DIN ISO 14091:2021, visualized in graphic in **Figure 5** based on Porst et al. 2022). As the DIN ISO 14091 standard is universally applicable to all types and sizes of "organizations" (e.g., financial institutions, companies, administrations), the guidelines are not customized to the specific context of the individual organization.

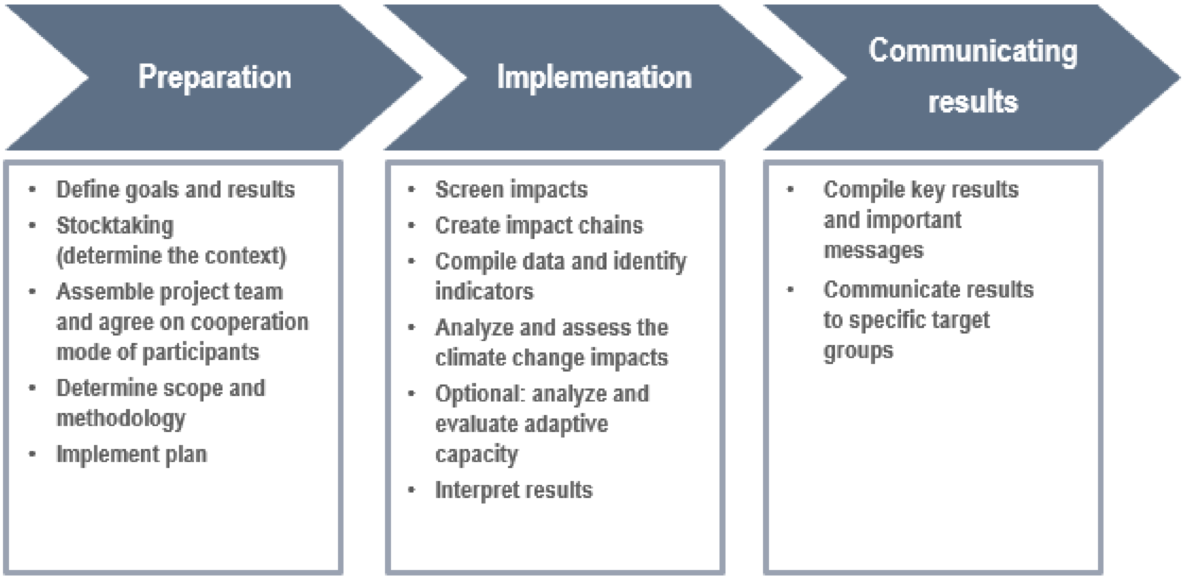


Figure 5 Phases of climate impact analysis
(according to Porst et al. 2022 based on DIN ISO 14091).

On behalf of the Federal Environment Agency, a guide was developed for local authorities based on DIN ISO 14091 on how the recommendations can be implemented in the local context. An illustrative procedure for the municipal context is provided, in particular, regarding the following points in DIN ISO 14091: i) collection and recording of relevant information, ii) transparency iii) impact screening and creating impact chains, iv) determining indicators, v) collecting and managing data, which includes data recording, evaluation of data quality and results as well as data management (Porst et al. 2022).

Since 2018, DIN ISO 31000:2018-10 "Risk Management – Guidelines" has provided guidelines to describe how companies can manage general risks. Risks should therefore be managed in an integrated, structured, comprehensive, tailored, inclusive and dynamic manner, taking into account the best available information as well as human and cultural factors (DIN ISO 31000:2018-10). The steps include i) risk assessment (risk identification, risk analysis, risk evaluation), ii) risk control and risk monitoring and iii) risk reporting. The company's context with its respective internal and external factors must be taken into account.

The extent to which an organization is affected by climate change, however, depends largely on various internal and external factors (e.g., geographical, topographical and hydrological initial situation at the location, organization [structure and processes] and operation, extent and probability of occurring impacts at the location, adaptive capacity). Therefore, each risk analysis is confronted with new initial framework conditions resulting in the non-existence of one universally valid solution (Hurrelmann et al. 2018; Eisenack et al. 2014; Freimann et al. 2014).

3.2. Need for Research and Action

The consequences of climate change affect not only operational business but also the strategic orientation of the company (see Supplementary Information Box 1 on page 23). For this reason, a sound examination of climate change impacts that takes into account various climate scenarios is necessary in order to facilitate adaptation and ensure the long-term sustainability of business models and strategic orientation (European Parliament and European Council 2022; BMWK 2022; Laranjeira et al. 2021).

The Task Force on Climate-related Financial Disclosures (TCFD), in its recommendations, has already formulated consideration of resilience in terms of business strategies and business models under changing climatic conditions, taking scenarios into account as a requirement (TCFD 2017). The TCFD also explicitly mentions consideration of several climate scenarios, including a scenario with a 2° C path or below, as a requirement for describing the resilience of the corporate strategy (TCFD 2017)[5]. As the TCFD requirements to consider climate change impacts were at first largely market-driven, the mandatory requirements of the EU Taxonomy Regulation and the Corporate Sustainability Reporting Directive (CSRD) described above can ensure that they will increasingly become the focus of attention in information disclosure (Europäisches Parlament und Rat der Europäischen Union 2022; Loew et al. 2021).

However, according to a study by the German Environmental Agency, hurdles in implementing future-oriented reporting still exist (Loew et al. 2021). Only four of the twenty DAX companies analyzed integrate climate change scenarios into their reporting and none of those companies issues statements on the climate-related resilience of its own company based on scenario analyses (Loew et al. 2021). To date, only a few companies are working with climate change scenarios, not to mention a range of scenarios. (Loew et al. 2021).

Hurrelmann et al. (2018) also describe the level of knowledge as low in terms of integrating climate protection and climate impact adaption into strategic planning and management processes. They additionally note decreasing research intensity into long-term developments, which especially includes adapting business strategies to the impacts of climate change. They attribute this decline to the increasing complexity and uncertainty of long-term planning horizons. Various factors have been identified as obstacles and barriers to integrating climate adaptation into strategic business processes: i) lack of knowledge, ii) lack of awareness, iii) lack of human resources iv) inadequate governance structures (Herrmann/Guenther 2017) v) lack of information about the nature, probability and timing of climate change occurrence as well as the impacts of climate change in terms of relevance to sustainability (Hurrelmann et al. 2018). The reasons for these barriers are identified as the decision-making process that

[5] "Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning (…) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario" (TCFD 2017, p.14).

determines the adaptation, the context in which the adaptation is established and the underlying system at risk (Eisenack et al. 2014).

Hurrelmann et al. (2018) identify the following phases from nearly all risk management guidelines:

1. problem identification, impact, vulnerability and risk assessment
2. selecting potential adaptation measures
3. evaluating the measures
    a. selecting the assessment method
    b. selecting assessment criteria
    c. procuring data
    d. prioritizing measures
4. implementing measures
5. monitoring and evaluating

A key finding from the collaboration between the Climate Service Center Germany (GERICS) and various practitioners is that many obstacles can already be found between Phases 1 and 2 described by Hurrelmann et al. (2018) (Groth et al. 2022; Groth and Seipold 2020; Groth and Seipold 2017). Furthermore, it is regarded as a challenge for companies to identify from the multitude of possible climate change impacts those that are relevant for their respective location or industry and then to derive and take appropriate measures as a result (Schlepphorst et al. 2023). In addition, comparing guidelines illustrates in the stage titled “Risk Management: Developing Measures and Implementation” that the guidelines either only develop measures or only describe this stage very briefly (Loew et al. 2021).

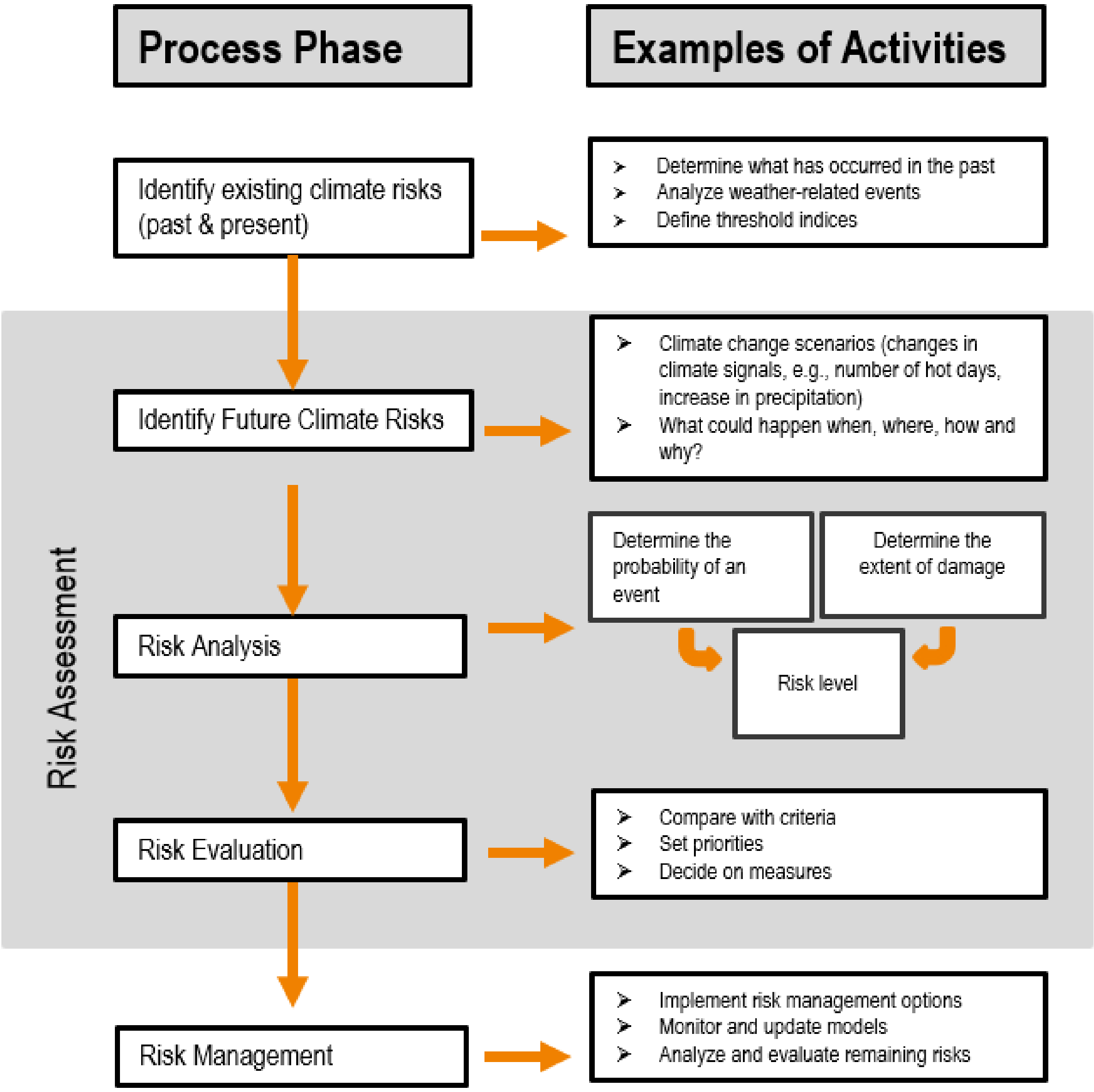


Figure 6 Risk management process and possible application for climate risks (modified according to Palin et al. 2021).

As **Figure 6** shows, there are many diverse steps along the risk analysis, assessment and management chain that require using and interpreting climate change information. With regard to possible company support offered for navigating this process in the form of guidelines aimed at managing climate-related risks, an analysis commissioned by the UBA demonstrates that only a few of such guidelines are explicitly geared for companies and are tailored to their needs (Loew et al. 2021). Efforts have been made to address this issue by means of three guidance documents recently: i) "Climate Risk Management 2050: Developing a Corporate Climate Risk Strategy Step-by-Step"[6] is a guideline that addresses risk management at the site along the supply and value chain and in regard to raw material procurement and sales markets (co2ncept plus n.d.); ii) the recommendation "How to perform a robust climate risk and vulnerability assessment for EU taxonomy reporting? - Recommendations for companies " (Dorsch et al.

[6] Translated to English from the originally German source

2022); iii) “Managing Physical Risks: An Introduction for Businesses”[7] is a guideline that focuses on the physical impact of climate change (Loew/Kind 2023).

Further challenges for the climate risk and vulnerability analysis required as part of the EU Taxonomy can be derived from the findings of the EU Technical Expert Group on Sustainable Finance (TEG) regarding the development process for the EU Taxonomy Regulation and the technical assessment criteria. Their final report on the EU Taxonomy (TEG 2020a) and the annex on methods (TEG 2020b) provide recommendations and examples for applying the approach to reporting on the Taxonomy-compliant share of economic activities. The expert group recognizes the difficulty that an adaptation taxonomy - in contrast to climate protection criteria - requires a process-based approach. This should also take into account specific factors related to context and location in order to be able to determine whether an economic activity contributes effectively to adaptation (TEG 2020b). Furthermore, the Technical Expert Group (TEG) on EU Taxonomy mentions a need for action in guidance with regard to handling climate-related information, decision-making in the face of uncertainty and in evaluating different climate adaptation options: “The TEG recommends that the Platform [on Sustainable Finance, authors’ remark], as a matter of priority, develops technical guidance on climate risk assessment, use of climate data and information, making decisions under uncertainties, and evaluating different adaptation options to aid the Taxonomy implementation (TEG 2020b, p. 27).

The recommendations of the German government's Sustainable Finance Advisory Council and the TCFD also identified the problematic short-term forecasting horizons in reporting, as did Carney. In addition to short-term statements, it has been recommended that medium-term (1-5 years) and long-term (10-20 years) statements should also be required, especially for the topics of climate change and sustainable development (Loew et al. 2021; Sustainable Finance Beirat der Bundesregierung 2020; TCFD 2017). This represents an additional reporting challenge, but one that is necessary in the face of the looming medium to long-term effects of climate change and the costs that have so far been transferred to the future in the form of limited or no longer existing opportunities for resource use and the preference for the present as described above. The Taxonomy expert group therefore also recommends that the assessment of climate-related risks should be updated at appropriate intervals, taking into account the latest information, technologies and approaches (TEG 2020b).

The finding that key figures and targets regarding climate change adaptation are not yet taken into account in terms of reporting (Loew et al. 2021) supports the assessment that businesses still require assistance in dealing with how to adapt to climate change impacts. Loew et al. therefore recommend that the following should be investigated: “[the] question of whether and why physical climate risks are underestimated, and if so, how this can be changed”[8] (Loew et al. 2021, p. 125). In addition, Brüggemann and Grewenig (2023) show that risk assessment based on prior experience can lead to an underestimation of climate change impacts. This makes it all the more important for businesses to deal with future-oriented information so that such misjudgment can be avoided. In this sense, Mahammadzadeh (2011) had already emphasized that, as part of the risk management process, obtaining and providing climate-

[7] Translated to English from the originally German source
[8] Translated to English from the originally German source

related information to support decision making is of relevance. Accordingly, the need for action or support for businesses can also be derived for identifying suitable climate change scenarios and working with those scenarios. Specifically, support is needed for transitioning from problem identification to impact, vulnerability and risk assessment, incorporating climate change information, and also to deriving, prioritizing and selecting potential adaptation measures. Furthermore, analysis specifically tailored to climate risks requires that the link be established with future-oriented climate change information, and methods are presented in which this information can be integrated into risk analysis.

It can therefore be stated that companies have so far only inadequately addressed long-term climate-related developments and the impacts on their business activities, their business models and their strategic orientation. At the same time, the requirements for businesses to deal with climate change impacts are growing due to regulatory requirements and increased interest from the public, customers, investors and various stakeholders. This demonstrates an urgent need for research and action with regard to integrating climate-related data into risk management and reporting processes. A process model is therefore described below as an approach to addressing the local and context-specific nature of climate change adaptation for businesses and the need to expand the risk analysis process by incorporating climate change information as outlined above.

INFORMATION BOX 1: Examples of climate change impacts for business models

Business models can be affected by climate change impacts in various ways. An obvious example here is of ski resorts in the Alps, where snow is increasingly absent due to the temperature changes and, as a result, the tourism industry is suffering (Pröbstl-Haider et al. 2021).

Nonetheless serious, less obvious impacts can also be linked to climate change. For example: vacation regions in the Mediterranean and popular vacation islands are increasingly affected by drinking water shortages. Related usage bans as well as heat waves and forest fires, which, in addition to affecting supply security and the well-being of both the local population and agriculture can also make a stay less attractive for potential guests. This hits areas that are heavily dependent on tourism particularly hard (Vogel et al. 2021).

Climate change impacts are also being felt in other sectors such as agriculture and viticulture. Here, business models will be threatened in the future if climatic changes occur that affect the cultivation or quality of certain crop rotations or varieties on which business models are based. In viticulture, for example, cultivation strategies must be restructured and diversified. Innovative business models must also be established in order to prepare for climate change impacts and to remain competitive (Niewind 2022).

Climate change has already led to widespread forest damage in Europe and Germany, and this trend is expected to intensify in the future (Knutzen et al., 2023; Cook et al. 2022; Senf and Seidel 2021). This means that forestry and the associated processing industry (e.g., sawmills) will be severely impacted. The resulting challenges are extensive, as both forestry endeavors and science are confronted with a number of fundamentally new questions and needs for action in order to deal with this change appropriately (Vacek et al. 2023). Due to the very long rotation periods of trees—one hundred years and more—the forestry sector is affected by the developments arising from climate change quite severely as well as in the long term. A specific need therefore exists to incorporate climate projection data into forestry decision-making processes in order to assist in ensuring future tree populations are climate-resilient and resilient overall.

Apart from the negative consequences on business models, new business areas are also emerging as a result of climate change impacts and the transition to a climate-neutral economy. Against the backdrop of high investment potential in climate protection and adaptation, great opportunities are visible. In North Rhine-Westphalia, for example, approximately 178,000 employees—or 30,5% of the workforce (2020)—were already counted as part of the “adaptation economy” related to climate adaptation technologies or services in 2021, with an upward trend expected. For Germany, a total of approximately 954,000 employees could be classified as part of the climate change adaptation economy in 2021 (State of North Rhine-Westphalia’s Ministry for the Environment, Nature Conservation and Transport 2022).

4. The GERICS Process model for Integrating Future-Oriented Climate Change Information into Business Establishments

The following illustrates a prototypical process that enables a scientifically sound discussion of climate change impacts while integrating the essential local and context-specific information.

The GERICS Process model was developed in the context of the GERICS Adaptation toolkit for companies[9] (Groth and Seipold 2017) for the prototype development of climate services by the Climate Service Center Germany (GERICS). Its purpose is to enable companies to identify, assess and evaluate how they themselves will be affected by climate change impacts today and in the future. It also identifies corresponding adaptation potential and possible measures to be taken in order to prevent or mitigate potential damage caused by extreme weather events and other impacts of climate change.

The method follows the structured process of risk management (Porst et al. 2022; BMUV 2021; Loew et al. 2021; DIN ISO 31000:2018). It takes into account the realization that few decisions are made based solely on a changing climate signal (Hurrelmann et al. 2018) and that it is therefore necessary to integrate climate change information into existing decision-making and risk analysis processes. The GERICS Process model incorporates the DIN ISO 14091 and DIN ISO 31000 recommendations and specifies the procedures, including relevant climate data for businesses. The GERICS Process model described below initially uses i) risk identification, ii) risk analysis, iii) risk assessment, iv) risk management, v) risk monitoring and vi) risk communication (DIN ISO 31000:2018). However, as climate risk consideration involves a number of special aspects (e.g., dealing with uncertainties, direct/indirect and cascading effects, acute and chronic risks), the GERICS Process model supplements the DIN procedure for risk analysis presented above and the phases identified by Hurrelmann et al. (2018) with the stages to be observed in analyzing and managing climate related risks as well as identifying, considering and utilizing relevant climate change information.

In addition to the transition risks, particular attention is also paid to the direct and indirect physical impacts (both acute and chronic), as they are still not given enough consideration in business decision-makers' perceptions. However, not only the flood disaster in the Ahr Valley in 2021, which caused risk to life as well as to supply chains (Trenczek et al. 2022c; Merz et al. 2021), but also the summer drought of 2022, with its negative impacts on agricultural crop yields and its negative impacts on the transport of goods via German inland waterways (Statistisches Bundesamt 2022), showed that businesses must already prepare for possible climate change impacts today.

The aim of the approach described below is to take a structured approach to analyzing the impacts of climate change so that examination can be undertaken of as many relevant business areas as possible regarding their vulnerability to both current and future climate change and the resulting impacts. This approach was developed to close the current gap between existing knowledge about expected climate change and the lack of awareness among decision-makers concerning how their own business is affected by climate change impacts. At the same time, it takes into account the increasing demands on businesses to prepare for

[9] https://www.climate-service-center.de/products_and_publications/toolkits/unternehmensbaukasten/index.php.de

climate change impacts and to disclose such information to investors and clients as part of their mandatory reporting.

The Process model outlined below is divided into the eight following phases (**Figure 7**): i) stocktaking ii) classification of how climate change affects the business, iii) identification, iv) supplying the required climate parameters v) facilitating the use of climate information (capability), vi) derivation and implementation of measures, vii) evaluation and viii) process solidification. In particular, phases 2-5 (classification, identification, supplying information and capability) of the GERICS Process model should come into play between Phases 1 and 2 as identified by Hurrelmann et al. (2017, see also Chapter 3.2). This is meant to overcome the challenge seen by businesses in identifying the most relevant affectedness on site for the company from the many possible climate change impacts. This will help support the transition from problem identification to impact, vulnerability and risk assessment while integrating climate change information and thus, to derive, prioritize and select potential adaptation measures.

Figure 7 GERICS Process model for taking climate change information into consideration in businesses enterprises (in-house visualization).

Due to locally specific and context-dependent affectedness of climate change impacts, the implicit knowledge of the business's decision-makers on the location and initial situation as well as on prior damage related to climate and extreme weather is taken into account as part of the status analysis. The aim of the GERICS Process model is to merge this knowledge with the available climate change information. This will enable company decision-makers to make well-founded decisions for developing a climate adaptation strategy or selecting suitable climate adaptation measures based on current and expected future impacts.

The Process model also offers businesses without sustainability management or established risk management an opportunity to effectively approach the topic of climate change adaptation. Building on the aforementioned conceptual risk analysis approaches, the procedure has been developed in such a way that a reference to integrating climate change information is established in each phase and the following questions are addressed:

1. what is the aim of this phase?

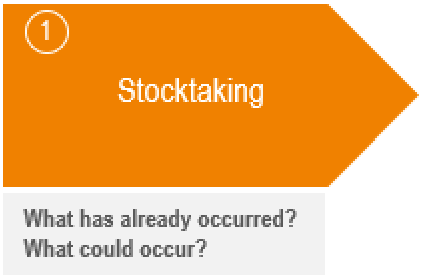
2. which questions need to be posed/answered in the phase in order to achieve the goal?

3. which methods can be used as a supporting element during the phase?

4. what is the relationship between the GERICS Process model phases and the EU Taxonomy requirements?

Furthermore, references to the risk management process phases (**Figure 6**) are established and supporting GERICS products for the respective phase are shown. This should facilitate the analysis and treatment of potential risks to be carried out independently based on scientifically sound and up-to-date climate change information.

4.1. Stocktaking



Phase 1 takes the form of **stocktaking** to identify possible events and associated damage, disruptions and delays based on previous experience, observations, meteorological data and implicit knowledge of all relevant company staff. Furthermore, externally available knowledge and information regarding possible impacts in the sector should also be take into consideration.

Events that directly affect the company, those that are already currently discernable and those that can be linked to climate change impacts are of particular importance. These events could occur, for example, along the entirety of the supply chain, in internal operations or along the distribution channels. In cooperation with company representatives, observed and/or known events are compiled. Future impacts must already be taken into account as well, whereby this phase in risk management is to be assigned to the risk identification phase. It is helpful to be aware of which assets must be protected, which business goals may not be achievable in the long term due to climate change impacts, and which impacts must absolutely be avoided from the company's perspective (UNDRR 2022).

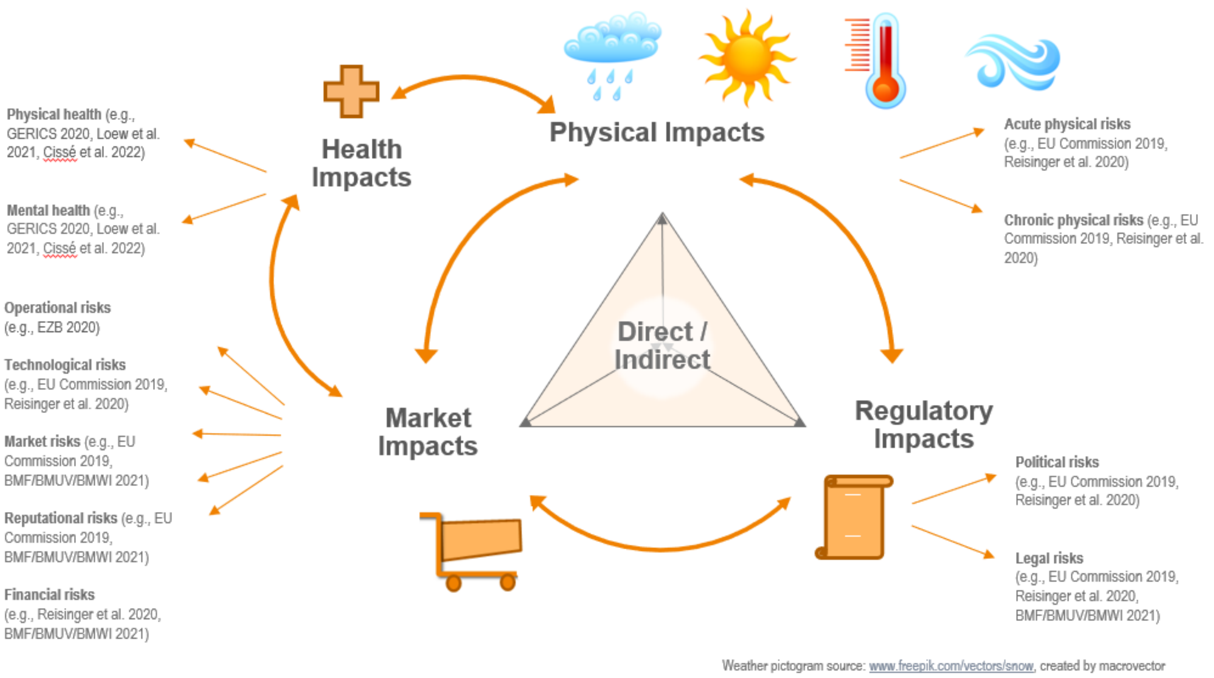


Figure 8 Impact levels of consequences due to climate change
(In-house visualization based on the sources cited. For further explanation see Appendix A).

As already described, climate change impacts companies in the form of both physical and transition risks. Therefore, all possible impact levels stemming from climate change impacts must also be taken into account as part of the stocktaking (**Figure 8**, see also **Appendix A** for further explanation). These impact levels can be broken down into physical, market and regulatory impacts, as well as health impacts affecting the company's staff in all upstream and downstream value creation processes. Furthermore, all impacts could affect businesses directly and indirectly. Within the framework of structured consideration regarding possible effects using this scheme, the impact levels mentioned above can be utilized to identify possible additional risks that are relevant to the company.

Within this stocktaking, not only the management knowledge, but also the knowledge of all relevant business areas should be utilized (Groth and Seipold 2017). This can be ensured as part of a workshop in which existing historical data are collected on weather and climate change-related disruptions and damage as well as foreseeable impacts based on this experience.

The following could be important central questions here:

- what disruptions or damages have occurred? what problems did they cause? where have they occurred?
- what consequences did they have for the company itself / for its areas of activity / for its clients?
- which meteorological quantity may have been the trigger?
- what disruptions / damages can be expected from future events?

The stocktaking also includes already existing information on the future development of climate parameters that may be relevant for the company. The GERICS Climate outlook at county level can be used as an initial rough estimate of possible changes in the future climate (Pfeifer et al. 2021, Rechid et al. 2021). With regard to future developments, the GERICS Climate outlooks at county level (Pfeifer et al. 2021) show, by using climate parameters, that an increase is to be expected, especially in temperature-related parameters (annual average of the near-surface air temperature, days with high temperatures above 25 or 30 degrees Celsius, tropical nights in the form of days on which the temperature does not fall below 20 degrees Celsius). While it is sufficient at this point to extract a rough overview of possible regional climate changes included in the GERICS Climate outlook at county level, a more detailed examination of the climate parameters takes place in Phase 3.

External data and information on climate impacts can also be included in the stocktaking. In some cases, heavy rainfall information or heavy rain hazard maps are already available at the municipal level, on the basis of which an initial assessment of flood risk locations is possible. Urban climate analyses can also be utilized, for example, for an initial assessment of heat hazards.

In the event that businesses have had little or no experience with the topic of climate change adaptation, the aim is to generate an understanding of the need to address the issue by highlighting possible impacts. Initially, an overview of general climate change impacts in the respective sector can be used here[10]. Furthermore, a literature review can be utilized to identify

[10] For example: Klimanavigator: https://www.klimanavigator.eu/index.php;

possible affectedness and impacts of climate change for the respective sector and to obtain information on how individual system elements in the respective sector were affected. GERICS created a corresponding prototype synthesis for the transportation sector, with a focus on public transportation (GERICS 2023, unpublished manuscript; see table section in **Figure 9**). In the table, the possible climate signals are combined with the company's potentially affected system elements (buildings, facilities, staff, products, infrastructure, supply chain, logistics, raw materials for products, etc.), and the possible affectedness is entered in the table fields.

	RAILWAYS	STREETS	VEHICLES
	Affectedness/Opportunity	Affectedness/Opportunity	Affectedness/Opportunity
HEAT (acute/chronic)	Damage to rails due to extreme heating: expansion and deformation of rails	Damage to road surfaces due to excessive heating: melting and cracking of the asphalt. Formation of ruts and waves, resulting in shorter usage periods for asphalt surfaces	Vehicles could heat up severely
			Increased cooling requirements resulting in higher energy demand
	Movement of rails		Deficient air circulation
	Limited signal functionality	Blow-Ups: sudden elevations in the road surface due to expansion of the underlying concrete slabs	Driver exposure
	Overheating of electrical infrastructure		
		Increased pollutant release from asphalt surfaces in warm temperatures and direct sunlight	
DROUGHT PERIODS (acute)	Infrastructural subsidence due to lower groundwater levels	Infrastructural subsidence due to changes in subsoil conditions	Water for cleaning vehicles could be restricted
INCREASED SUMMER DRYNESS (chronic)	In combination with heavy rainfall: increased risk of landslides	In combination with heavy rainfall: sediment transport due to erosion on dry soils	
	In combination with storms: sandstorms		
	Increased risk of forest and hillside fires along stretches of the route	Increased risk of forest and hillside fires along stretches of the route	
	Infrastructural subsidence due to changes in subsoil conditions	Infrastructural subsidence due to changes in subsoil conditions	
TEMPERATURE INCREASE (chronic)	Lower maintenance costs in winter	Lower maintenance costs in winter	Altered requirements for cooling vehicles
	Extended construction season	Extended construction season	

Figure 9 Table excerpt for systematically considering potential affectedness/opportunities in the transportation sector due to climate change impacts (GERICS 2023, unpublished manuscript).

In addition, a supplementary visual representation of damage images and affected locations can also be helpful in identifying the possible affectedness for your own business (procedure described in more detail in **Information Box 2**, see page 32). Furthermore, working with climate impact chains as part of the risk analysis is often recommended (EEA n.d.; Porst et al. 2022; UBA 2022; DIN ISO 14091:2021; EEA 2018b; GIZ and EURAC 2017, UNDRR 2022).

Klimalotse: https://www.umweltbundesamt.de/dokument/klimalotse-vorlage-uebersicht-klimawirkungen;
Climate Adapt: https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies

The climate impact chains illustrated by UBA (2016) for various sectors provide a structured overview of all possible impacts for the sector under consideration. In addition, the (impact) relationships between individual climatic influences and the respective impacts (climate impacts) as well as between the climate impacts themselves are mapped (UBA 2016). These can also be developed as a visualization of potential climate change impacts on business activities or the company's own industry sector.

Possible climate hazards to be assessed in terms of a minimum requirement as part of a risk and vulnerability analysis compliant with EU Taxonomy are listed in Appendix A of Annexes I and II of the Delegated Regulation to the EU Taxonomy Regulation (Europäische Kommission 2021a) (**Figure 10**).

	Temperature-related	**Wind-related**	**Water-related**	**Solid mass-related**
Chronic	Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
	Heat stress		Precipitation or hydrological variability	Soil degradation
	Temperature variability		Ocean acidification	Soil erosion
	Permafrost thawing		Saline intrusion	Solifluction
			Sea level rise	
			Water stress	
Acute	Heat wave	Cyclone, hurricane, typhoon	Drought	Avalanche
	Cold wave/frost	Storm (including blizzards, dust and sandstorms)	Heavy precipitation (rain, hail, snow/ice)	Landslide
	Wildfire	Tornado	Flood (coastal, fluvial, pluvial, ground water)	Subsidence
			Glacial lake outburst	

Figure 10 Classification of climate hazards to be considered as a minimum requirement in the climate risk and vulnerability analysis. This is in accordance with the technical screening criteria for the "climate change adaptation" environmental objective in Appendix A of Annexes I and II of the Delegated Regulation to the EU Taxonomy Regulation (Europäische Kommission 2021a).

INFORMATION BOX 2: Illustrative procedure: a visual presentation of damage images and impacts at locations

A suitable procedure, described below, was developed in cooperation with a business firm and applied in practice as an example.

Together with a logistics company, GERICS analyzed one location as an example of how the firm could be affected by climate change impacts. The physical impacts of “extreme precipitation”, “heat” and “wind”, which were identified after evaluating the corresponding “GERICS Climate outlook at county level”, were integrated into a satellite view of the location in the form of graphic symbols. This approach illustrated the spatial occurrence of possible impacts triggered by the physical affectedness identified at the location. Furthermore, possible adaptation measures that are generally possible for those identified impacts were compiled in a supplementary presentation and this information was then shown to the logistics firm’s decision-makers during a workshop. The objective was to use the visualization described above to better communicate the topic of climate change adaptation, which they themselves initially judged to be "abstract”. After the workshop, the participating decision-makers found the method described to be extremely comprehensible and useful.

4.2. Classification

The aim of Phase 4.2 is to assess the affectedness identified in Phase 4.1 in regard to whether they require immediate action and how they should be prioritized in relation to each other. This filters out which potential impacts are critical and therefore especially relevant to the firm's objectives. It therefore highlights the issues that could potentially impact the firm's operations, productivity and performance in terms of strategic, political and/or stakeholder-relevant objectives. For example, a weighted decision table **(Figure 11)** or a matrix **(Figure 12)**, as illustrated below, is to be utilized for this task. This phase in risk management is to be assigned to the problem analysis stage.

		Affectedness 1		Affectedness 2		Affectedness 3	
Criteria	Weighting	Rating	Weighted	Rating	Weighted	Rating	Weighted
Costs (direct)	0	0	0	0	0	0	0
Costs (indirect)	0	0	0	0	0	0	0
(Business) strategic goals	0	0	0	0	0	0	0
(Business) political goals	0	0	0	0	0	0	0
Goals relevant to stakeholders	0	0	0	0	0	0	0
Other goals (e.g., provision for the common good)	0	0	0	0	0	0	0
	Points	0		0		0	

Figure 11 Example of a weighted decision table (in-house visualization)

Basic criteria are defined in advance and evaluated in terms of their respective relevance using weighting on a scale of 1 to 10. The criteria of all identified impacts are then analyzed. The following questions can typically be utilized to weight the respective row in the decision table (**Figure 10**):

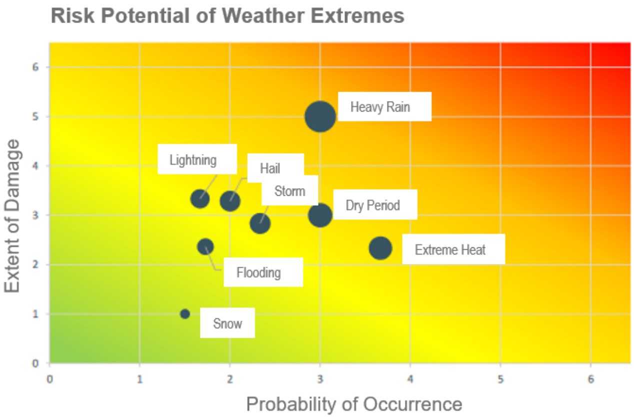
- What direct costs - that is, costs explicitly arising from climate change impacts - have been incurred? How was revenue affected?
- What indirect costs were incurred as a result of damage repair or the temporary or permanent loss of certain company infrastructure, sectors and activities?
- Did the impact have consequences for the business strategy, business policy or business model?
- Did the impact (temporarily) affect achievement of defined business goals?
- Did the impact affect expected profitability?
- Did the impact affect employees?
- Did the impact affect the company's contribution to the common good or to other business partners?

The impacts that the company believes should be particularly avoided or mitigated in accordance with its own objectives or due to a lack of adaptive capacity can also be weighted higher than others in this phase. After weighting, the impacts that should be taken into further consideration can therefore be prioritized. Knowing that sufficient adaptation capacities are available, a number of risks can also be accepted in prioritization compared to others if they can be adequately addressed when they occur.

Alternatively, the most important potential impacts can also be evaluated using a risk matrix and the criteria probability of occurrence and extent of damage (**Figure 12**). The questions that must be answered individually for each climate parameter are as follows:

- How often can the potential impact be expected to occur?
- What extent of damage could the occurrence entail?

This means that the impacts with a high probability of occurrence and a high extent of damage are visualized in the matrix in the upper right area, which can also be identified as a hazard area by the coloring, as in the example. This type of visualization can simplify presentation of results to those not involved in the process.



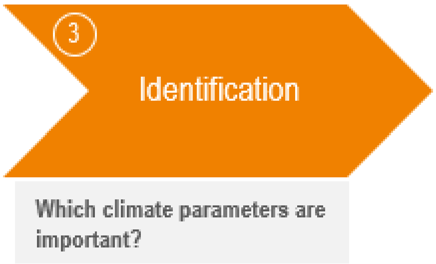
Probability of Occurrence	
1 - unlikely	less than every 30 years
2 - conceivable	approx. every 10 to 30 years
3 - seldom	approx. every 5 to 10 years
4 - occasionally	approx. every 2 to 5 years
5 - frequently	yearly
6 - certain	several times a year
Extent of Damage	
1 - very low	0 to 50,000 euros
2 - low	50,000 to 100,000 euros
3 - moderate	100,000 to 500,000 euros
4 - heavy	500,000 to 1,000,000 euros
5 - very heavy	1,000,000 to 5,000,000 euros
6 - existential threat	more than 5,000,000 euros

Figure 12 Risk matrix example for extreme weather events with a scale breakdown according to the probability of occurrence and the extent of damage (translated based on co2ncept plus n.d.).

It should be noted that the scale definition and the damage assessment are subjective. It is therefore vital at this point to document the underlying explanations for classifying the scales and assessing the risk in a transparent and plausible manner.

As part of the EU Taxonomy, the climate hazards to be taken into consideration are specified in Appendix A of Annexes I and II of the Delegated Regulation to the EU Taxonomy Regulation (see also **Figure 10**). Prioritization therefore does not mean that climate hazards that are less relevant at first glance should not be examined further. Climate hazards that are not relevant to the firm due to their geographical occurrence or due to other reasons must in all cases be carefully documented and justified. The method for recording potential climate hazards and their possible impacts on business activities helps the company to assess the climate hazards in a structured manner and can then be utilized to document this procedural phase at the same time.

4.3. Identification



The key climate parameters that are important for a more precise analysis of future impacts are now determined for the identified impacts and the climate hazards (**Figure 10**) with high relevance as defined by the EU Taxonomy.

The question to be answered at this point is:

Which climate parameter(s) is/are needed to make statements possible on the current status as well as on the development of the identified climate hazard(s) or potential impact(s)?

The GERICS Climate outlooks at county level can be utilized to identify important climate parameters. This is because they show the possible future development of seventeen climate parameters altogether assuming different emission developments based on eighty-five regional climate model simulations. The parameters are also subjected to an expert judgement on the data's robustness (Pfeifer et al. 2021). The relevant climate data include, for example, the air temperatures expected today and in the future, the number of heat days and tropical nights, the number and length of droughts and the number of frost days, humid days and days with heavy rainfall (for an explanation of the climate parameters, see also Appendix B). Combinations of days on which certain thresholds are exceeded or not met can also be important. A tropical night, for example, will not necessarily have serious consequences - but a series of tropical nights combined with a certain number of heat days will have even more of an impact. The following provides an overview of the parameters available in the GERICS Climate outlook and their definitions (see also Appendix B). If needed, these parameters should be adapted or supplemented for the specific company.

The GERICS Climate outlooks at county level provide relevant information for all 401 counties, urban municipalities and regions in Germany. The climate information is based on the climate simulations available in the ESGF data archive (ESGF=Earth System Grid Federation) at the time the respective climate outlooks were prepared; the climate simulations used are all listed in the GERICS Climate outlooks (Pfeifer et al. 2021).[11] Simulations for three different representative concentration pathways (RCPs) are taken into consideration for this purpose. Ranges for the relevant climate parameters and their possible developments up to the middle and end of the century are provided. These serve as a reference point and as a foundation for decision-making in regard to necessary company action in this area of concern. They therefore meet the aforementioned quality criteria for climate change information (see also Chapter 3.1).

Methodologically, a possible overview of the climate parameter´s development can be provided in this phase. This can be integrated into the existing impact tables and marked, for

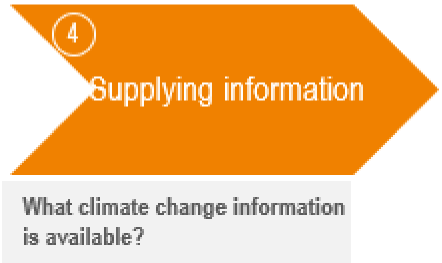
[11] https://esgf-data.dkrz.de

example, in a color code, making it clear what climate hazards are likely to increase in frequency/intensity. This phase can also be assigned to the risk assessment step.

The EU Commission calls for a list of climate hazards to be examined as part of a risk and vulnerability analysis, taking “into account the state-of the-art science for vulnerability and risk analysis” (European Commission 2021, Appendix A of Annexes I and II of the Delegated Regulation to the EU Taxonomy Regulation; see also Chapter 3.1 and Chapter 4.1). In a recommendation, the UBA has further differentiated the climate parameters listed there (Dorsch et al. 2022).

It is possible to integrate the specified climate parameters into the GERICS Process model. The climate risks that the company must handle are operationalized here with future ranges for the occurrence of relevant climate parameters or a combination of these. The GERICS Climate outlooks therefore provide regional climate scenarios for the assessment “using the highest available resolution, state-of-the-art climate projections across the existing range of future scenarios" required by the Delegated Regulation (European Commision 2021). These scenarios are specified in a footnote: “Future scenarios include Intergovernmental Panel on Climate Change representative concentration pathways RCP2.6, RCP4.5, RCP6.0 and RCP8.5.” (European Commision 2021).

4.4. Supplying Information



In phase 4, the next step is to compile, process and supply additional climate change information customized for the company's needs. In this phase, businesses gain an overview of available climate change information as well as the quality of that information. This provides companies with the relevant data to help them consider the expected future climate impacts and their relevance in regard to action areas identified within the company. The current and future changes in climate parameters must be taken into account by the businesses as needed. At this point, depending on the availability of climate expertise within the company, it may be advisable to obtain external knowledge and expertise on the use and quality assessment of climate scenarios and climate change information. This phase can also be allocated to the risk assessment stage, whereby it forms the foundation for risk management.

In this phase, decision-makers can use various available GERICS Fact Sheets with climate change information on specific parameters. For example, the GERICS Country Climate Fact Sheets[12] developed in cooperation with the KfW Development Bank are available. The Climate Fact Sheets provide the key climate characteristics in concise form for individual countries or regions around the world. They synthesize information on the characteristics and development of various climate indices such as temperature, precipitation or water balance. Furthermore, they contain statements on climate history and current climate characteristics.

In addition, further prototypes have been developed as part of the Fact Sheets - for example, a format relating to a specific city (City Series[13]). They also contain examples of in-depth modeling, such as urban climate modeling and rainfall-runoff modeling, which can be used to analyze climate change information for the purpose of identifying and visualizing possible hot spots. The utility of the Fact Sheets to support climate adaptation processes was confirmed in workshops with companies.

The climate change information must also be taken into account in combination with information on:

- the business location (altitude, degree of soil sealing, materials, surrounding land use)
- the location of critical infrastructural elements
- existing hazard and risk maps
- the company's employees and clients

[12] https://www.climate-service-center.de/products_and_publications/fact_sheets/climate_fact_sheets/index.php.de
[13] https://www.climate-service-center.de/products_and_publications/publications/detail/078167/index.php.de

- products and processes and their dependence on deliveries and suppliers
- the buildings and local conditions such as access roads, recreation areas, warehouses, production facilities, offices
- any additional factors

This information can also be visualized as a map due to its geographical nature (UNDRR 2022). This helps to better classify the risk of being affected by changes in climate parameters. Last but not least, it is also vital to determine the business's adaptive capacity. All of the following can play a role here: regular employee training and exercises in regard to knowledge transfer and process flows in case of extreme weather events, business strategy adaptation, the availability of financial resources for immediate measures, access to the necessary technology but also to the corresponding organizational structures and human resources. These measures therefore can facilitate preparation for possible impacts, handling those impacts, recovering quickly from the impacts and adapting to them in the long term (UNDRR 2022).

Observation data on previous damage or weather phenomena at the relevant locations or along the supply chain are, as already mentioned in Chapter 4.1, also important indicators for identifying geographical focal points of possible impacts and the necessary corresponding measures.

4.5. Capability

Phases 1-4 were aimed at identifying, analyzing and evaluating climate change impacts, and phases 5-8 focus on anchoring the procedure within the business along with facilitating and evaluating risk management.

Phase 5 focuses on the capability of the company's decision-makers to utilize climate change information. User-specific formats ensure that the information provided can also be interpreted by company representatives, blended with local information and translated into a coordinated requirement for action. It is only in this way that they can ultimately be utilized in the company's decision-making processes. The following suitability criteria for different objectives must be taken into account when selecting a suitable format:

- intended depth of engagement with the information
- intended size of the participant group(s) to be informed
- time available

Possible approaches/formats are shown in **Figure 13**, arranged according to the degree of interactivity:

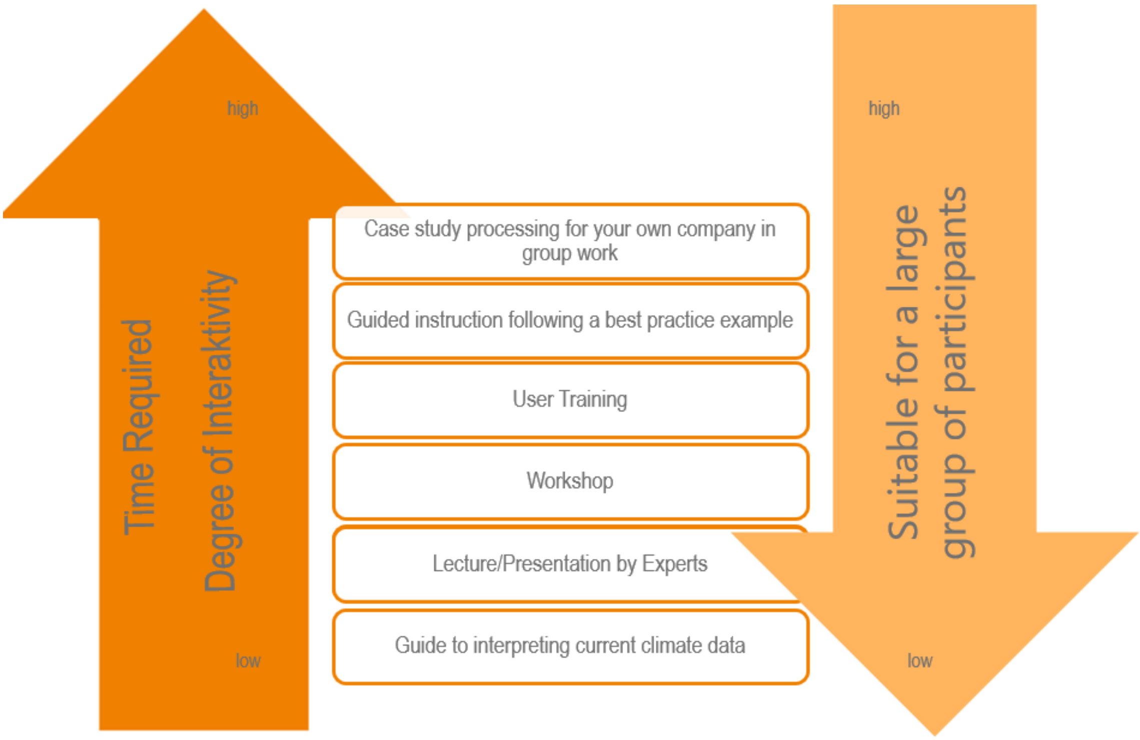


Figure 13 Possible approaches for involving staff and transferring information (in-house visualization).

In this phase, it is advisable for businesses to train several staff members in handling the data so that they can still make the best possible use of the available climate change information in the event of personnel changes. Depending on which criterion is especially vital for the business, one of the following formats can be used for this purpose.

A guide to interpreting climate change data is suitable for gaining a relatively quick overview on the use of climate data. This is particularly appropriate for self-determined work with climate change information and does not require any explicit prior knowledge.

For example, a presentation on the relevant climate outlook can be provided - possibly in the form of a webinar, but this only offers limited potential for interaction. Such a format is particularly suitable if time is limited and as an introductory option for simultaneously informing as many staff members as possible. A presentation should at least be accompanied by getting acquainted with the “GERICS Climate outlook at county level” by the participants before the event, which should also include the following specific questions:

1. Which climate parameters do you consider relevant for your company based on the GERICS Climate outlook at county level?

2. What impact(s) can you derive for your company (e.g., buildings, infrastructure, products, employees, customers, etc.) from the information in the GERICS Climate outlook at county level?

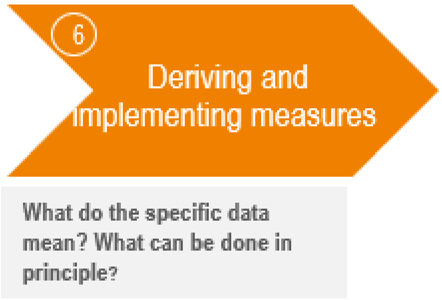
3. How or for what purpose would you or will you use the data/information from the GERICS Climate outlook?

4. Is a detailed analysis necessary and can the findings obtained with the climate change information be the starting point for further modeling (e.g., urban climate analysis using an urban climate model, rainfall runoff modeling, see also Bender et al. 2023a; 2023b)?

Lectures can also be used for workshops and user training, but combined with practical and in-depth exercises. Here, for example, the participants should independently identify the relevant climate change information for a described initial situation, determine the expected changes from the Climate outlook and prepare them as part of a briefing for decision-makers. GERICS experts can provide assistance here. User training can also result in synergistic effects. Participants learn how to use the information from the GERICS Climate outlook at county level, while GERICS representatives receive important information on the practical needs and obstacles regarding how to utilize and integrate climate data into processes. This allows use of the GERICS Climate outlooks at county level to be assessed and the products to be further enhanced based on participant feedback.

In order to learn and deepen the application of climate change information, guided instructions to recreate a best practice example or a case study based on your own business are time-consuming to prepare, but they are highly illustrative approaches for supporting the application of climate change information for a fictitious or real planning situation. You can choose to work based off a best practice example if you know of a successful case from your own industry or company. The presentation method using a case study should be chosen if a location or process in your own company - where conversions/changes are planned already - is to be used as a window of opportunity in demonstrating how climate change information can be taken into account.

4.6. Deriving and Implementing Measures



Continuing from the Capability phase, phase 6 involves deriving, prioritizing and implementing measures. These measures are used to address the affectedness identified in analyzing climate change information. By implementing the measures, a company can increase its capacity to adapt to climate change impacts. The aim is therefore to make management, staff, locations, logistics and products "climate change fit”. This influences the business’s strategic orientation, locations and investments. Analysis and implementation of adaptation measures is intended to avoid the risk of stranded assets - assets that have become worthless in a short period of time, primarily due to environmental and/or climate-related factors. Expertise from the specialist departments within the company is particularly necessary here in order to identify measures and create or increase acceptance for implementing them within the company. This phase is classified as part of risk management as a component of risk handling. Possible strategies include risk avoidance, risk minimization, risk transfer, and acceptance of residual risk (DIN ISO 31000:2018).

Answering the following questions has proven useful in this phase:

1. What measures exist and which ones have proven successful in practice?

2. What experiences have others encountered in implementing measures?

Here, the first step is to review known databases of measures (e.g., the Tatenbank des Umweltbundesamtes[14], Climate-ADAPT Case study explorer and Climate-ADAPT Case studies booklet[15]) to get familiar with adaptation measures in the sector. As an example for the transportation sector - and public transportation in particular - a table of measures was developed as a prototype based on the table that shows the affectedness of different business areas using the same pattern. There, corresponding adaptation measures from the literature are listed according to the different climate impacts and business sectors.

Furthermore, the question arises as to how to prioritize measures and which climate change impacts should first be addressed. At this point, the need for more in-depth modeling as a decision-making aid can be identified, such as rainfall-runoff modeling or urban climate

[14] https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/projekte-studien
[15] https://climate-adapt.eea.europa.eu/en/knowledge/tools/case-study-explorer
https://climate-adapt.eea.europa.eu/en/about/climate-adapt-10-case-studies-online.pdf

modeling to identify and visualize those areas particularly affected (see also Bender et al. 2023a and Bender et al. 2023b).

In order to avoid the risk of maladaptation or shifting the risk from one sector to another, a set of measures should be drawn up within the company for different areas of business activity and divided into short, medium and long-term measures. Measures should also be identified that exhibit synergies in combination with other measures or that have a positive effect even without the occurrence of climate impacts (also known as "no regret measures"). Weighting can be made according to different factors to determine the priority of the measures. Such factors include: synergies with other measures, added value even without the occurrence of climate change impacts, contribution to risk reduction, environmental, social and economic influence, feasibility, time required for implementation and development of efficacy, costs, life cycle analysis, maintenance and upkeep costs, flexibility, increase in adaptive capacity for handling climate change impacts in areas where deficits are observed, etc. When utilizing different criteria to evaluate measures, the UBA[16]'s generic criteria for good adaptation practice can be used. These criteria include efficacy, robustness, sustainability, financially viability, positive side effects and flexibility. Possible key questions are derived from these criteria as follows:

- Efficacy: Can the measure effectively and permanently minimize the identified risk?
- Robustness: Would the measure work under various climate conditions?
- Sustainability: Does the measure take equal and balanced account of the economic, environmental and social dimensions? Does it contribute to sustainable development?
- Financial viability: Can the measure be implemented with limited financial expenditure? Compared to other measures, is it the one that promises the greatest benefit at reasonable cost?
- Positive side effects: Can the measure achieve positive side effects for the environment, health, society, quality of life, etc., regardless of whether expected climate change occurs or not?
- Flexibility: Can the measure be adapted, upgraded or expanded depending on the occurrence of climate changes?

Based on the selected criteria, a list or overview of measures is then created that can be prioritized according to their time horizon and expected performance. A structured approach is recommended - for example, an evaluation matrix can be used. At this point, qualitative statements on sensitivity and the potential capacity for adaptation through practiced procedures, processes and precautionary measures should also be included in evaluating a

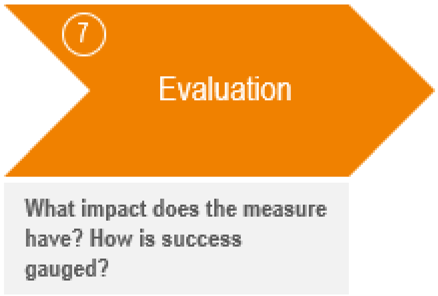
[16] https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/werkzeuge-der-anpassung/tatenbank/kriterien-guter-praxis-der-anpassung#kriterien-guter-praxis-der-anpassung

measure. The underlying risks can also be classified according to whether they can be tolerated or not (UNDRR 2022), which should be additionally included in prioritizing measures.

Lastly, the identified measures are implemented within the company. All standard company procedures must be taken into account here.

Action planning also plays a vital role in the context of the Technical Assessment Criteria of the EU Taxonomy for the “climate change adaptation” objective. Appendix A of Annexes I and II of the Delegated Regulation to the EU Taxonomy Regulation stipulates that an “assessment of adaptation solutions that can reduce the identified physical climate risk” must be carried out and an adaptation plan for implementing the measures must be drawn up and implemented (European Commission 2021).

4.7. Evaluation



Phase 7 is important for iteratively and recursively reviewing the success of measures as part of an evaluation as well as the process itself.

For example, the following methods can be used for this purpose:

- impact analysis (planning analysis)
- evaluation specific to the measure
- examining the outcome and impact (e.g., using indicators)
- monitoring the measure's efficiency
- monitoring the measure's efficacy
- impact simulation
- surveys
- interviews (semi-structured, focus groups)

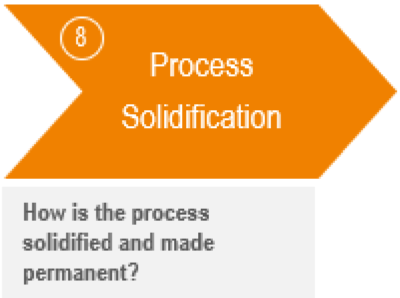
In view of the uncertain, non-linear and long-term nature of climate change (Dinshaw et al. 2014), a number of special features must be taken into account when evaluating adaptation measures. For example, Dinshaw et al. (2014) mention the challenge in attributing success to the implemented measure and defining baseline and target values for adaptation measures. Bours et al. (2015) emphasize the difficulty in measuring the success of climate adaptation measures in contrast to evaluating or measuring the success of climate protection measures, especially in the short term. As the occurrence of extreme weather events and gradual climate change and their impacts cannot be predicted with precise accuracy in terms of location and time, it is difficult to evaluate a locally implemented adaptation measure in regard to the damage it avoids. In addition, a simple before-and-after data comparison carries the risk of excluding other influences that also affect the measured variables at the location (Bours et al. 2015). Furthermore, adaptation measures should often be seen as part of a larger adaptation strategy, the effectiveness of which can only be comprehensively and conclusively evaluated as an overall perspective.

From previous research on evaluating climate adaptation measures or concepts, it is known that monitoring and evaluation are often neglected and that in the field of climate adaptation there are difficulties in operationalizing the measure's impact in concretely measurable key metrics (e.g., Bours et al. 2015). To overcome this challenge, Dinshaw et al. (2014) recommend a combination of qualitative and quantitative evaluation methods. This way, the local context can be taken into account by including optional indicators in the indicator set alongside core indicators (Bours et al. 2015). Pre-defined objectives can also be reviewed using key metrics. The measure's impact as well as disruptions in the supply chain and the resulting costs can be documented (Lühr et al. 2014). If applicable, this makes it possible to recognize that a measure needs improvement or that a supplementary measure must be introduced to support achieving the objectives. Analyzing the awareness within the company in regard to the topic of climate change adaptation can also be a component of the evaluation and can be recorded and documented through surveys (Hurrelmann et al. 2018).

The existing experience and knowledge gained from evaluation research is often insufficiently utilized and taken into account (Bours et al. 2015). For this reason, it can be useful to again seek stakeholder cooperation from within the fields of science, consulting or measurement technology in this process stage in order to carry out this impact analysis. It is important for the business and the orientation of the climate adaptation strategy to do so based on the current state of technology and research.

In addition to evaluating the actual adaptation measures or strategies (outcome evaluation), an evaluation of the process must also be distinguished. To this end, the question must be investigated as to what extent all relevant knowledge carriers have been involved and where further optimization is conceivable in incorporating additional or new climate change information. If the stages in the Process model are carried out in cooperation with scientific and social stakeholders, transdisciplinary collaboration can also be the subject of the evaluation (Schuck-Zöller et al. 2018). In the GERICS Process model, this would be the dialog-oriented process in which locally specific information and existing knowledge within the company are combined with research findings, and/or the climate information is integrated into the business processes for risk analysis. Continuous reflection within the transdisciplinary team is essential in evaluating transdisciplinary research (Schuck-Zöller et al. 2018). An evaluation, however, can also be carried out retrospectively after the joint processes of integrating climate change information into business processes and strategy have been completed (Schuck-Zöller et al. 2018).

4.8. Process Solidification



Lastly, it is important to permanently integrate the Process model into the company's organizational structures and processes. All relevant content from the entire procedure can be regularly updated in this way. The GERICS Process model can be linked to existing quality management cycles within the company, such as a PDCA (plan-do-check-act/adjust) cycle. This describes an iterative process of:

1.) information collection and monitoring based on key performance indicators (KPI), which are achieved during the process implementation
2.) identifying and analyzing deviations
3.) determining the causes of deviations
4.) making the necessary adjustments (see Musayelyan et al. 2020 and others).

The GERICS approach can also be integrated into existing management systems for this purpose.

One of the success factors identified by the World Economic Forum for increasing resilience in organizations is to understand resilience less as a goal and more as an ongoing journey. Accordingly, a recurring learning and adaptation effect stemming from stress test exercises and crises that have actually been experienced is needed in order to emerge stronger as well as to better be able to react to changing circumstances. Additionally, this understanding makes it easier to repeatedly question one's own perceptions and identify blind spots, as well as to take the necessary further measures (World Economic Forum 2022). It is also advisable to integrate a learning process so that a flexible and iterative approach facilitates reflection and process improvement (Dinshaw et al. 2014).

In view of the EU Taxonomy requirements, taking process solidification and reporting seriously can result in a competitive advantage. By integrating future-oriented climate change information into business practices early, opportunities arising from climate change impacts for business models and new products can be recognized and harnessed.

5. Conclusion and Outlook

The GERICS Process model presented in this report introduced a procedure for integrating future-oriented climate change information along the phases of a risk management process using prototypical GERICS products. On the one hand, the report contributes to closing the identified gap at the transition between problem identification and derivation of measures. On the other, it offers an approach to overcome the previously lacking future-oriented focus of business action while at the same time taking into account the new requirements for financial and sustainability-related reporting that stems from regulations at the EU level. It does so by integrating climate change information into risk management.

This process model, which was developed conceptually and tested using prototypes, is currently being implemented and further developed in close cooperation with businesses. A main objective here is to combine the (implicit) knowledge that decision-makers within companies possess about previous affectedness with current observation data and climate change information on possible future climate change. This facilitates structured analysis of the respective company divisions regarding possible affectedness from current and future climate change impacts. Based on this joint process development, decision-makers should be equipped to create sound climate strategies, develop suitable adaptation measures and implement these measures by working through the process.

The individual phases and their objectives as well as the questions to be addressed within them were presented, and tools in the form of possible methods and already existing GERICS prototype products were shown so that businesses can move through the phases with support.

The EU Commission has adopted a classification system for economic activities ("EU Taxonomy") in order to align business investments more closely with climate protection and climate risks in the future (TEG 2020a; 2020b). This means that financing businesses in Europe is also influenced by this EU Taxonomy. It is intended to encourage companies to disclose the extent to which certain business activities contribute to the adaptation and can thereby increase the flow of capital to businesses that participate in the adaptation (Kind and Kahlenborn 2020). As the requirements are important to many businesses, the chapters also contain references to the relevant requirements arising from the EU Taxonomy for the corresponding procedural stage.

An advantage of applying the GERICS Process model is that it enables a business to handle the operational affectedness of climate change, which is also of great importance in the context of dealing with the classification system requirements for environmentally sustainable economic activities ("EU Taxonomy") that came into force in 2022. It not only contributes to standardizing climate-related reporting, but also addresses Measure 12 of the Sustainable Finance Strategy: "Supporting the real and financial economy in improving the risk management of physical climate risks[17]" (BMF/BMU/BMWI 2021). In addition to damage prevention and limitation, the knowledge gained from working through the Process model can also contribute to achieving the transformation towards a resource-conserving, sustainable,

[17] Translated to English from the German original source

climate-neutral and climate-adapted society, which especially addresses Sustainable Development Goals 9, 11 and 13.

In the prototype development of business-related climate services, it has proven beneficial in the past for GERICS practice partners to have the provided climate change information explained by GERICS staff. This is in order to identify the climate parameters that are important for the company and relate them to various areas that are potentially affected along the company’s value chain (production, supply, storage, sale, demand, reputation). In their feedback, the practice partners noted that a kind of “translation aid” would be needed for future activities without GERICS support in order to relate the findings from, for example, the Fact Sheets to the company’s areas of activity and make them usable for decisions in regard to adaptation options. This requirement formulated by the businesses gave rise to the GERICS Process model.

As mentioned above, the GERICS Process model is a prototypical process that can vary in practice depending on prior knowledge and the already existing data foundation and observation data; it can always contain feedback loops from one phase to another. The following success factors have been identified in the application to date: in applying the Process model, close and trusting cooperation between the internal and external partners involved is crucial for success right from the beginning. In addition, the success of the application depends on involving the relevant individuals in the company with their experience and implicit knowledge when evaluating and weighting the action areas to be prioritized and the development of suitable adaptation measures.

The authors see possible further development of the Process model in enabling a generalized approach to interpreting climate data regardless of the availability of an expert. This could be a storyline based on an example or a guideline for interpreting the GERICS Climate outlooks at county level. A corresponding guide is already partially included in the GERICS Climate outlook at county level (explanation of climate indices, climate projections and robustness as well as the climate change diagrams shown in the Climate outlook: What Can I Read in a Climate outlook?). The guide is currently being supplemented based on queries and feedback collected from practical applications of the GERICS Climate outlook at county level (FAQ collection) so that in the future, the GERICS Process model will also provide a format that companies can use independently to initiate climate adaptation processes within their establishment.

In addition, an added value of the Process model is seen as promoting the development of options with a transformative character for adapting to the consequences of climate change (new forms of cooperation, opening up new fields of activity, cross-organizational thinking and action, new and systemic thinking about adaptation requirements, involving other relevant actors to manage climate risks) as part of a transdisciplinary co-production process.

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7. Appendix A: Possible Impacts of Climate-Related Risks for Companies, Including Explanations

Possible impacts of climate-related risks for companies, including explanations. (In-house compilation and categorization (first column) based on the sources named in the second column)

Physical consequences of climate change impacts	**Physical risks** (e.g., TCFD 2017, EU Commission 2019) ▪ The climate-related consequences that result for the areas of raw material extraction, supply chains, production, administration and warehouse locations, as well as for the health and occupational safety of the staff. These exist both acutely in the form of extreme weather events and in the form of gradual processes, such as sea level rise and changes in precipitation patterns
	Acute physical risks (e.g., EU Commission 2019, Reisinger et al. 2020) ▪ Due to certain event-driven incidents, occurring at short notice, especially weather-related events such as storms, floods, fires and heat waves: damage to facilities, supply chain interruption
	Chronic physical risks (e.g., EU Commission 2019, Reisinger et al. 2020) ▪ Long-term, often gradual changes in the climate and their impacts (e.g., temperature changes, rising sea levels, reduced water availability, changes in the yield capacity of soils, etc.)
Health consequences of climate change impacts	**Physical health** (e.g., GERICS 2020, Loew et al. 2021, Cissé et al. 2022) ▪ Risks to staff members who work outdoors or in spaces that heat up considerably when exposed to sunlight ▪ Direct risks to life and safety for staff members from extreme weather events such as storm surges and flooding, heat waves and forest fires, winter storms and heavy rainfall

	▪ Physical health impacts stemming, for example, from heat exposure and poor sleep due to heat can reduce performance and staff availability as well as increase absenteeism ▪ Increased exposure to sunlight and UV radiation increases the risk of skin and eye diseases ▪ Indirect risks due to damage to infrastructure and facilities, e.g., pollutants can flow into rivers or seep into the surrounding soil and thus contaminate drinking water
	Mental Health (e.g., GERICS 2020, Loew et al. 2021, Cissé et al. 2022) ▪ Deterioration in mental health due to experiencing or observing the impacts of climate change on others ▪ Post-traumatic stress disorder, anxiety, panic attacks, sleep disorders, concentration and learning disorders, depression, aggression, and other issues can be consequences of extreme events.
Impacts of the transition to a climate-friendly economy	**Transition Risks** (e.g., TCFD 2017, EU Commission 2019) ▪ Risks faced by businesses in the transition to a low-carbon and climate-resilient economy. For example: a company's own economic approach, business model or products that have been successful to date may be called into question in the future economy. This could, for example, arise due to higher CO_2 prices for fossil fuels, higher energy efficiency requirements for building structures and production facilities, and a change in demand for products that are particularly climate-friendly. Furthermore, negative consequences may arise if the company's activities fail to comply or deviate from the climate targets set forth in laws and regulations. These consequences could therefore include political, legal, technological, market and reputational risks.
Market consequences stemming from climate change impacts	**Operational Risks** (e.g., EZB 2020) ▪ For example: disruption in maintaining business operations due to climatic and environmental events

	Technological Risks (e.g., EU Commission 2019, Reisinger et al. 2020) ▪ For example: when relying on a technology that is then not available or ready for use to achieve a result ▪ In addition: in the event that a competitor's own technology, which is harmful to the climate, is replaced by a technology with a less harmful impact on the climate
	Market Risks (e.g., EU Commission 2019, BMF/BMUV/BMWI 2021) ▪ For example: the shifting purchasing decisions of consumers and business customers to other products and services or limited availability of raw materials in the desired quality or quantity
	Reputational Risks (e.g., EU Commission 2019, BMF/BMUV/BMWI 2021) ▪ For example: the difficulty of attracting and retaining customers, employees, business partners and investors if the company has a reputation for damaging the climate or fails to comply with existing reporting obligations in this regard
	Financial Risks (e.g., Reisinger et al. 2020, BMF/BMUV/BMWI 2021) ▪ Risks for a financial institution or investor investing in a company ▪ Risks of a company becoming unattractive with regard to lending ▪ Risks in terms of loss in value of assets and real estate
Regulatory consequences of climate change impacts	**Political Risks** (e.g., EU Commission 2019, Reisinger et al. 2020) ▪ For example: energy efficiency targets, CO_2 pricing, political strategies to promote sustainable land use, climate targets within sectors, and elimination of subsidies for climate-damaging activities can lead to losses in value and the loss of business models ▪ Changes in the regulatory framework (water prices, extraction permits, development plan requirements) for

	adapting to climate change can also include risks for business activities and business models
	Legal Risks (e.g., EU Commission 2019, Reisinger et al. 2020, BMF/BMUV/BMWI 2021) ▪ For example: risk of legal disputes/lawsuits or damage claims caused by failure to adapt to climate change Liability risks due to a failure to avoid harmful impacts on the environment or people or by failing to assess climate-related impacts before making decisions or by failing to comply with mandatory reporting requirements ▪ The variety of reporting requirements (CSDR, EU Taxonomy, construction law, environmental impact assessments) also entails risks stemming from additional efforts required in overseeing and coordinating all requirements

8. Appendix B: Climate Parameters from the GERICS Climate outlook at county level (Pfeifer et al. 2021)

Key Parameter	Definition
Temperature	The temperature here is the air temperature near the ground (2 m above the ground). The values for the annual mean and seasons are calculated based on daily mean temperature values. The values for the seasons are calculated for the meteorological year: the temperature for winter is the average of all days in the months of December, January, February; for spring in the months of March, April, May; for summer in the months of June, July, August; and for fall in the months of September, October, November.
Summer Days	Number of days per year with a maximum daily temperature of more than 25 °C.
Hot Days	Number of days per year with a maximum daily temperature of more than 30 °C
Tropical Nights	Number of days per year with a minimum temperature of more than 20 °C.
Frost Days	Number of days per year with a minimum temperature lower than 0 °C.
Late Frost Days	Number of days per year with a daily minimum temperature below 0 °C between April 1 and June 30.
Ice Days	Number of days per year with a daily maximum temperature below 0 °C.
Days over 5° C	Number of days per year with an average daily temperature greater than 5 °C. These days are sometimes also referred to as "growing degree" days. However, other factors, such as soil moisture, radiation and nutrient availability, are also decisive in determining whether vegetation grows on a particular day.
Maximal Duration of Heat Periods	Maximum duration (in days) of periods of consecutive days with a daily maximum temperature above 30 °C.
Precipitation	The precipitation values are calculated based on daily precipitation amounts and are given as average monthly precipitation totals for the year and the seasons in mm per month. They include both liquid and solid precipitation, that is, rain and snow. The seasonal precipitation amounts are

	calculated for the meteorological year (see explanations on temperature).
Dry Days	Number of days per year during which the amount of precipitation (rain and snow) is less than 1 mm.
Precipitation ≥ 20 mm/day	Number of days per year on which precipitation (rain and snow) reaches or exceeds 20 mm.
95^{th} percentile of the precipitation	Daily precipitation, the amount of which is exceeded on 5% of all days per year with precipitation above 1 mm.
99^{th} percentile of the precipitation	Daily precipitation, the amount of which is exceeded on 1% of all days per year with precipitation above 1 mm.
Climatic Water Balance	Annual average of the daily difference between precipitation and evaporation in mm/d.
Wind Speed	Average wind speed per year in m/s.
Humid Days	Number of days per year with a water vapor partial pressure greater than 18.8 hPa. The vapor pressure is calculated from daily values of the near-surface air temperature and the relative humidity using the Magnus equation.

9. Definitions / Explanation of Terms
(based on the sources named in parentheses, in accordance with the focus of this report and relating to the respective business context)

Climate Hazards (based on IPCC 2023b: Annex I: Glossary)	The term describes the potential occurrence of events or trends that are threatening today due to climate changes that have already occurred, or to those in the future due to changed climate conditions. These hazards may involve loss of life, injuries or other health consequences, as well as damage or loss of property, infrastructure, livelihoods, providing services, ecosystems and environmental resources.
(Climate-related) Risks (based on IPPC *2023b: Annex I: Glossary)*	The potential for negative impacts on human and ecological systems. In regard to climate change, risks can arise from climate change itself and its consequences, or conversely, it could arise from how people deal with these risks. The extent to which these risks are actually reflected in damage or loss depends on the actual occurrence of the climate hazard and also on whether economic, social or cultural values, investments, services, the health and well-being of a company's staff are exposed to this hazard at the location where it occurs (exposure) and how susceptible a company is to it (vulnerability). Furthermore, the extent to which a company is prepared for the occurrence of such risks and is able to handle them (adaptive capacity) also plays a role. The probability of occurrence and the extent of climate hazards are subject to uncertainty. In addition, exposure, vulnerability and adaptive capacity can also change over time due to socio-economic changes and decision-making as well as risk-management.
Exposure (based on IPCC 2023b: Annex I: Glossary)	In regard to companies, this term describes the presence of infrastructure (buildings, sites, logistics), economic activities (production, delivery, provision of services, etc.), assets and resources as well as staff members in certain areas or circumstances that could be negatively affected by the occurrence of an event or a change.

Adaptation Capacity (expanded based on IPCC 2022b)	In regard to businesses, adaptive capacity describes the ability of a system, an organization and/or individuals to respond to climate change impacts and the resulting potential damage and consequences, as well as to absorb, avoid or mitigate these consequences from the outset, during or after the event, or to take advantage of the resulting opportunities. The capabilities associated with adaptive capacity include, for example, mindset, organizational and operational processes, financial means and human resources. Furthermore, the adaptive capacity is determined by relevant knowledge, available technologies and, ultimately, the suitable countermeasures as well as the practice of safely handling potential climate impacts.
Vulnerability: (based on IPCC 2023b: Annex I: Glossary)	This describes the predisposition of a system/business to be adversely affected by negative climate change impacts due to its characteristics. If, for example, a system is insufficiently protected against possible impacts and is therefore vulnerable, or if a business has insufficient capacity to adapt to and deal with climate change impacts, it results in high vulnerability to climate change impacts.
(Possible) affectedness (authors' own definition*)*	This term covers possible climate change impacts on the entire business system and the consequences—for example: on raw materials, at sites, along supply chains, in relation to the health and well-being of staff members and on the sale of products and services. On the one hand, the real affectedness is influenced by the actual occurrence and extent of a climate-related event or a change. On the other, the afectedness is influenced by the exposure and vulnerability as well as the company's adaptive capacity. In addition to the actual affectedness in the form of damage, restrictions in relation to achieving business goals or to providing business activities or even losses, the potential affectedness can also help as a theoretical, mental framework. This serves to facilitate consideration of possible damage patterns and effects on the various system elements of the company in advance and prepare for them at an early stage.
Climate risk and vulnerability analysis (based on DIN ISO 14091:2021)	A climate risk and vulnerability analysis comprises a survey, assessment and evaluation of the risks and opportunities associated with climate change for a business or a business-related area (e.g., municipality, county, federal state or country). It incorporates current,

	scientifically sound and appropriate data, knowledge and experience as well as the combination of local/sector or company-specific knowledge with climate change information. Within this framework, the potential climate change impact today and in the future, as well as exposure and adaptive capacity, are methodically summarized. This is followed by identifying and prioritizing action areas and deriving possible measures to avoid, mitigate or handle the issue with residual risks. The aim is to record the vulnerability to potential climate change impacts as a basis for adaptation planning and risk management. The analysis can additionally include tracking the development of the risk and monitoring the adaptation as well as communicating the risk assessment.

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