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Final report

Potential Impact of Climate Change on Financial Market Stability

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Details on the members of the advisory board can be found in the appendix.

Disclaimer:

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Acronyms and abbreviations

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie – (French) Agency for Environment and Energy Management
BaFIN	Bundesanstalt für Finanzdienstleistungsaufsicht - (German) Federal Financial Supervisory Authority
BMBF	Bundesministerium für Bildung und Forschung – (German) Federal Ministry of Education and Research
BMU	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit - Federal Ministry for the Environment, Nature Conservation, Construction, and Nuclear Safety
CAPEX	Capital Expenditure
CAPM	Capital asset pricing model
CISL	Cambridge Institute for Sustainability Leadership
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
COP21	2015 United Nations Climate Change Conference
CU	Carbon Underground
EBIT	Earnings Before Interest & Tax
EC	European Commission
ECB	European Central Bank
EEA	European Economic Area
ETF	Exchange Traded Fund
EU	European Union
EUR	Euro
FFI	Fossil Fuel Indexes
FSB	Financial Stability Board
GDP	Gross domestic product
GDV	Gesamtverband der Deutschen Versicherungswirtschaft e. V. – German Insurance Association
GHG	Greenhouse gasses
IPCC	Intergovernmental Panel on Climate Change
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt hours
MW	Megawatt
MWh	Megawatt hours
NPV	Net Present Value
OECD	Organization for Economic Cooperation and Development
PIK	Potsdam Institut für Klimafolgenforschung – Potsdam Institute for Climate Impact Research
ROV	Real options valuation (or ROA - real options analysis)
t	Ton
TCFD	Task Force on Climate-related Financial Disclosure
UBA	Umweltbundesamt – German Environment Agency
UNEP-FI	United Nations Environment Programme - Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USA	United States of America

USD	US Dollar
VfU	Verein für Unternehmensführung – Association for Corporate Management
WRI	World Resources Institute
WWF	World Wide Fund for Nature

Executive Summary

Climate risks have a vast potential to impact financial markets. Through the process of moving towards the 1.5° to 2°C target, fossil fuel assets can lose value. One way is through more frequent natural catastrophes, which can lead to significant losses in asset value alongside insurance losses. Within the scope of this study, it was investigated whether climate changes results in a risk to financial market stability. To this end, the CO_2 emissions financed by German equity funds were analysed, and a series of expert interviews were conducted, focussing on potential short to medium term risks. The study distinguishes between physical risks (e.g. increased storm damage) and transition risks (e.g. regulation that severely limits fossil fuel consumption). Liability risks are not considered.

Whilst physical risks appear to represent a very low risk for financial market stability in Germany in the short to medium term, transition risks are considerably more relevant. A sudden adjustment of CO_2 prices or other abrupt regulatory interventions would lead to significant losses on the financial market, which, in conjunction with other risks, could lead to a destabilization of the financial market. This is why an orderly transition to a low-carbon economy, which is financially stable, clear and longer-term policy signals are desirable. However, further analysis and research, for example with regard to the concentration risks of individual actors and risks for asset classes beyond public equity and impact chains is required.

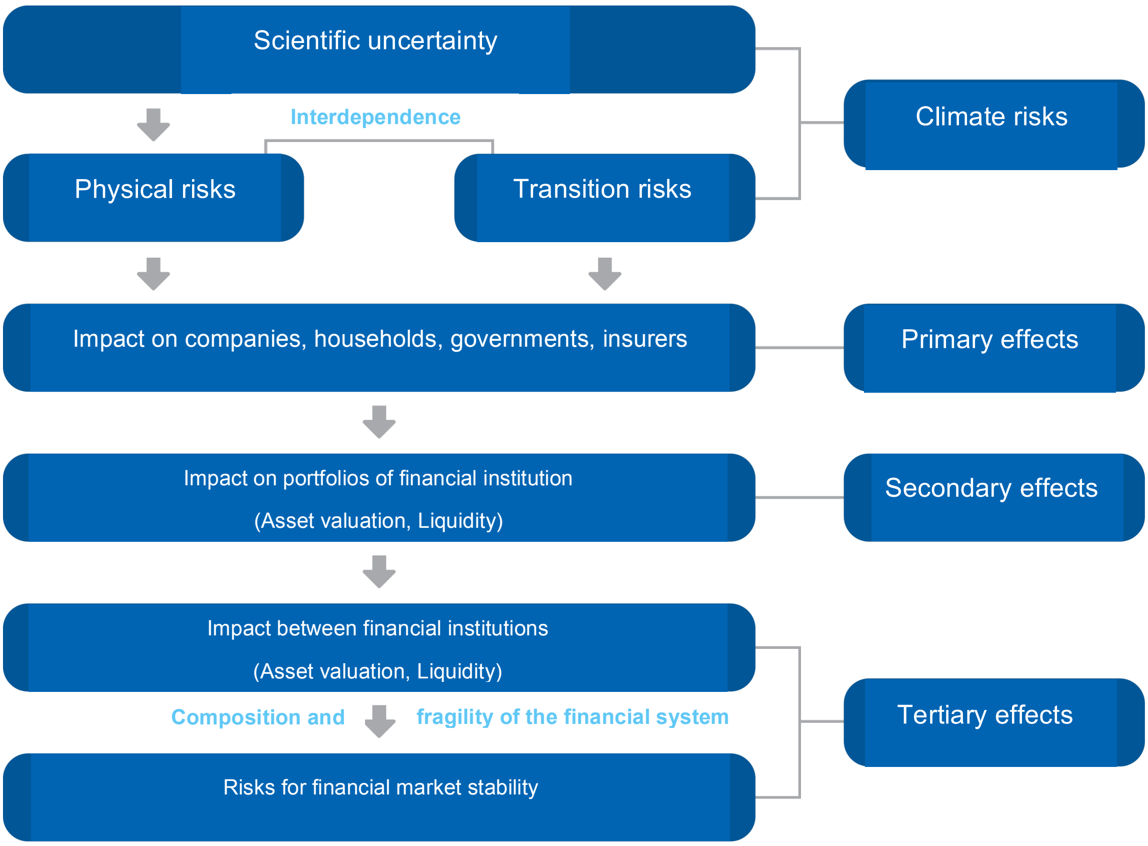
Detailed Summary

Climate risks have a vast potential to impact financial markets. Through the process of moving towards the 1.5° to 2°C target, fossil fuel assets can lose value. One way is through more frequent natural catastrophes which can lead to significant losses in asset value alongside insurance losses. Within the scope of this study, it was investigated whether climate changes results in a risk to financial market stability. To this end, the CO_2 emissions financed by German equity funds were analysed, and a series of expert interviews were conducted, focussing on potential short to medium term risks. The study distinguishes between physical risks (e.g. increased storm damage) and transition risks (e.g. regulation that severely limits fossil fuel consumption). Liability risks are not considered.

Relationship between climate risks and the financial market

Both physical and transition risks[1] can have multiple impacts on the financial market. These can be directly on the financial market (primary effects), indirectly through investment by financial market players in impacted financial assets (secondary effects), or further indirectly through investment in impacted financial market actors (tertiary effects). See Figure 1.

Figure 1: Relationship between climate risks and potential impact channels



Source: South Pole, partly based on Bowen and Dietz (2016)

[1] Liability risks are not a separate part of the study.

This study examines four subject areas: physical risks, transition risks, pricing of risks and information required by investors for sensible management of these risks.

Physical risks of climate change

Physical consequences of climate change, such as extreme weather events, can cause direct risks for the financial market in the form of higher and more volatile losses for the insurance industry and possible operational risks such as the closure of bank branches in case of extreme events.

Unexpected events that are extremely unlikely could put financial-system relevant insurers in a financially difficult situation. On top of this, extreme weather events involve indirect risks for the financial markets in the form of uninsured losses or unpaid insurance losses in the real economy. This could further affect the financial economy through unexpected depreciation, higher default risk of loans, and, in extreme cases, downgrading the creditworthiness of companies and states. See Figure 2.

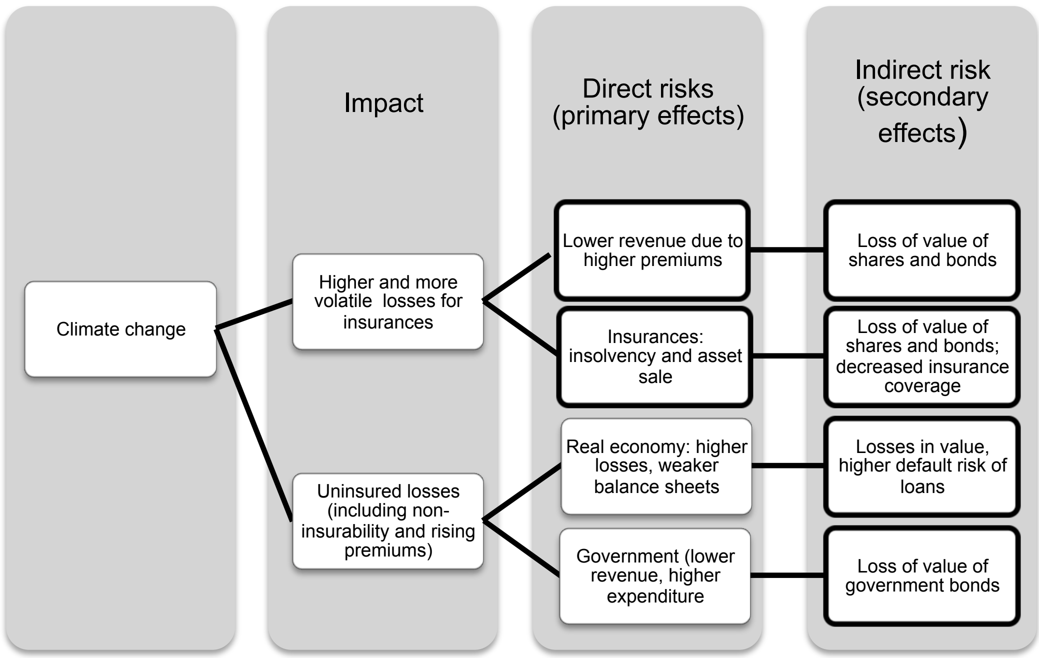
In the short and medium term, it is very unlikely that the physical effects of climate change could cause a significant risk for the financial market stability in Germany and Europe. The insurance industry can adapt relatively well to direct risks since insurance premiums can be adjusted on an annual basis and the risk capital can be adapted continuously. A greater risk for the insurance industry is that changes in the probability of extreme events with very high losses are not directly reflected in the insurance models due to the use of historical-statistical data. This risk exists even without climate change but may be exacerbated by its implications.

Significantly rising losses due to climate change could mean that certain weather risks are no longer insured as premiums become too expensive. This increases the indirect risks for the financial market (secondary effects) through uninsured losses, which can cause losses in value for companies and a greater default risk of loans. In some cases, governments could react with aid programmes for such losses, which in turn would burden public finances. Massive indirect risks due to uninsured damages, leading to a downgrade of the creditworthiness of a government, are more likely for poorer and smaller countries, and therefore not very relevant for the German financial market, which is only marginally invested in bonds and shares of such vulnerable countries.

Due to its gradual development, the physical impact of climate change beyond extreme events hardly poses a short or medium term risk to the financial market stability, especially compared to extreme single-day losses on the stock market. However, more extreme changes cannot be ruled out in the longer term, since there are considerable uncertainties, particularly in the case of warming beyond 2° to 3° Celsius. The politically set 1.5° to 2° limit therefore primarily serves as a precaution against such scenarios.

Financial implications of physical risks can be exacerbated by the international interdependence of the German economy, among other things with regard to value chains and sales markets. However, there is only very little research available regarding those effects.

Figure 2: Key potential impacts of physical risks on the financial market stability



Source: South Pole Group

Transition Risks

Due to the low emissions of the financial actors themselves, physical risks (primary effects) are only marginally relevant. Transition risks primarily impact the financial market (secondary effects) through investments of financial market actors in affected companies. Companies can be affected, for example, by increased prices of CO_2 and other greenhouse gas emissions, by stricter regulation of their energy efficiency, or by a decrease in the demand for emission-intensive products (e.g. cars with a conventional internal combustion engine). The potential magnitude of transition risks can be estimated with the help of CO_2 price scenarios and assumptions about the general depreciation of investments in certain industries. The quantitative analysis within the framework of this study focuses on the examination of the financed emissions for a sample of German equity funds. Financed emissions allocate investors with a share of the annual emissions proportionate to their investment. If an investor owns 10% of the market capitalization, 10% of the company's annual emissions will be allocated to them as financed emissions.

If the examined equity funds had to bear their financed emissions (Scope 1 and 2) in the oil and gas, energy, commodities, and industrial sector, this could lead to costs up to EUR 4 billion, representing 4.5% of the investments in these sectors and 1.2% of the total investment (assumption: EUR 99 per ton CO_2 based on to the mean value of the EPA[2]).

Scope 3 emissions would be a further important analysis perspective but were not investigated in this study. Furthermore, equity funds only represent a fraction of the financial market.

Under the assumption that based on the high level of integration of the financial market with general macroeconomic development, the economic costs of climate change, amounting to approximately 2-5% of the GDP, are applicable for the German financial market. This would correspond to losses of EUR 262 - 655 billion per year. However, individual companies and

[2] In the context of this study, to estimate the possible CO_2 prices, the approach for macroeconomic costs is used. It is based on the prices for climate impact costs of 80 EUR/tCO_2e in 2010, as recommended by the EPA, but interpolated for the year 2014, which corresponds to 99 EUR/tCO_2e (based on the recommended prices for 2010 and 2030).

sectors could be affected even more. In case of six energy and industrial companies in the DAX, for example, when factored in completely, UBA believe the CO_2 costs could exceed 10% of the total earnings, when assuming social costs of carbon.[3] The variance of the effects of CO_2 prices on companies is very large.

The analysis results are subject to a number of limitations: it is difficult to estimate the probability of the occurrence of transition risks and how suddenly such a shock might occur, since this depends on the probability and predictability of regulation in Germany and other countries[4]. Furthermore, the 2-5% represents a one-time loss and does not take any adjustment measures into account. The above figures, therefore, represent a rough estimate of an extreme scenario. Moreover, the sample of the German equity fund market does not allow for an actor-specific assessment of concentration risks and the resulting impact chains.

A transition risk of up to 2-5% of the financial market alone is very likely to present only a low risk to the stability of the financial market, especially considering historical volatilities. Even with a loss in value of 5% in one day due to massive climate political interventions, none of the 10 highest single-day losses of the DAX in the last 30 years would be reached.

The considered secondary effects could, however, lead to problematic consequences through tertiary effects. This is dependent on the structural characteristics of the financial system, e.g. its interconnectedness and general stability. Moreover, the effects per sector and company could vary considerably. These effects have been studied based on literature research and expert interviews, but not quantified in the study.

Pricing climate risks

Transition risks and physical risks can theoretically be integrated into existing investment assessment procedures (such as discounted cash flow models). In practice, however, missing data and significant uncertainty about the effects of climate change and regulatory interventions do not allow for the risks to be factored in completely.

Today's CO_2 pricing within the German financial market – and thus the inclusion of transition risks – focuses on longer-term investments as well as actors with high CO_2 emissions, especially in the energy supply and industrial sector. From a financial market stability point of view, factoring in the transition risks should primarily be based on realistic expectations regarding future CO_2 prices. However, it is not possible to assess whether today's pricing of future CO_2 is based on realitistic expectations, as standardised scenarios of future carbon regulations are missing. The only observation that can be made, is that today's carbon pricing by investors (if there is any) is based on current CO_2 market prices and therefore significantly lower than the social costs of CO_2 emissions, which could serve as possible benchmark for future regulations.

This leads to a possible risk to financial market stability: if policy-makers were to increase the CO_2 costs to the social costs in a short period of time, a "transition shock" could occur as the new, politically determined CO_2 prices have not been taken into account for investment assessments and therefore, many investments would drop significantly in value.

A direct factoring-in of physical damage hardly takes place outside the (re-)insurance industry due to its complexity and the not yet significantly increased damages. However, the physical risks associated with the insured companies are factored into the insurance premiums. According to the interviews, financial institutions and smaller insurers rely on the knowledge and insight gained by larger players, particularly reinsurers.

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[3] Own calculation based on the South Pole Group database (CO_2 emissions scope 1 & 2 and revenue per company in 2014) and EPA (2012b) for CO_2 costs (interpolation for 2014 based on values for 2010 and 2030)

[4] This is important because „carbon leakage“ can occur, i.e. the effect that companies relocate their production from countries with structural regulations into those with fewer restrictions.

Information required by the financial market

The analyses on physical risks and transition risks have mainly focused on primary and secondary effects of climate change, as well as Scope 1 and Scope 2 emissions of assets in equity funds for reasons of data availability and quality. However, to provide comprehensive information about possible systemic financial market risks and risks to individual players, information on tertiary effects, CO_2 data for asset classes beyond equity fund investments, data on Scope 3 emissions, i.e. emissions from the entire value chain, as well as analyses of corporate returns for different climate scenarios are required. The analysis of today's pricing also concluded that there is a lack of information within the financial market; in particular related to future CO_2 prices. This shows that there is a need for more comprehensive information and analysis to enable investors to better understand climate change and to reduce the risks of climate change to financial market stability.

In theory, there are clear ideas as to which information would be needed to allow investors to correctly assess and factor in the risks on corporate level in the context of climate change, thus ensuring the efficient allocation of financial resources by market actors (see Table 1). A number of investors are already assessing climate change as a risk and include climate change issues in investment analyses for risk mitigation purposes (see, for example, Portfolio Decarbonisation Coalition). In practice, however, not all the necessary information can be obtained, either because it is not available or not sufficiently standardized.

In general, there is great uncertainty about two pieces of core information: the longer-term physical effects of climate change and the likelihood and design of 2° Celsius-compatible regulatory interventions. Even the Paris Agreement[5] has failed to provide a clear picture of future CO_2 prices. Many investors today do not expect the 2° Celsius-target to be implemented politically. However, if this assessment is incorrect and policy-makers opt for very abrupt regulatory interventions to comply with the Paris Agreement, this entails a potential risk to financial market stability.

For equities and corporate bonds, there is an increasingly broad database regarding CO_2 emissions and potential losses in value resulting from climate change, but it is highly fragmented. Uniform standards are missing for both the data provided by companies as well as the analysis of the financial impact of different scenarios. Moreover, in-depth analyses, e.g. about the extent to which profit margins are endangered by climate change and strategies for dealing with possible future risks and shocks, are often available only in the context of tailor-made projects.

Data standards could simplify the integration of data into existing investment processes and IT systems, and the development of uniform scenarios for scenario analyses would create comparability. Although there are a growing number of analysis perspectives, few of them lead to an explicit quantification of the *financial* risk.

[5] 195 governments adopted the final agreement of the United Nations Intergovernmental Panel on Climate Change (COP21) on December 12, 2015 with the goal of limiting the rise increase global average temperature (well below 2° Celsius) and efforts to limit the temperature increase to 1.5° Celsius (UNFCCC, 2015).

Table 1: Necessary information for investors

Type of climate risk	Aggregation level	Data points
Physical risks	Physical investments	– Investment-specific turnover and location – Climate sensitivity of the investment and upstream/downstream investments
	Asset class / country	– Insurance level and risk mitigation strategies – This also includes banks etc., i.e. financial market actors
	Portfolio	– Climate sensitivity based on stress test scenarios
	Sector	– Climate sensitivity based on stress test scenarios
Transition risks	Physical investment/ country	– Production costs and turnover, location – Size/capacity/production – Emission intensity
	Asset class, country	– Capital investment plan – Climate Research & Development Expenditures – Market positioning – Emission intensity
	Portfolio	– Climate sensitivity based on stress test scenarios – Emission intensity
	Sector	– Climate sensitivity based on stress test scenarios – Emission intensity

Source: South Pole, aspect data points based on 2° Investing Initiative (2016a, 2016b)

Recommendations

Recommendations for the management of physical risks based on the results of this study:

- Promotion of the dialogue between the insurance industry, financial market and supervisory body regarding dealing with highly unlikely, but very damage-intensive extreme events.
- Discussion on an international level (e.g. within the framework of the Financial Stability Board) regarding the possibilities and the benefits of coordinated and standardised measurement of the handling of physical risks of climate change by the insurance industry and the real economy.

Recommendations for the management of transition risks based on the results of this study:

- Reliable policy signals regarding timing and design of the planned transition to a low-carbon economy. Any abrupt change of climate policy signals should be avoided.
- Support for the implementation of publicly available data and measuring methods for asset classes beyond public equity, especially for bonds, loans, and real estate.
- Discussion on an international level (for example, within the framework of the Financial Stability Board) regarding the possibilities and benefits of coordinated, standardised scenario analyses of transition risks.

Recommendations for closing major gaps in the research on climate risk:

- In-depth analysis of possible network effects between financial market actors who are directly or indirectly affected by climate change.
- Studies of insufficiently studied asset classes, for which climate risks are of particular importance, especially corporate bonds, government bonds, loans, and real estate/mortgages.
- Studies on sectors with significant emissions in the upstream and downstream value chain.
- In-depth studies on the interdependence of the German real economy and finance industry with physical risks and their political and economic consequences in regions that are most vulnerable to climate change.

In summary, physical risks in the short to medium term represent a very low threat to the financial market stability in Germany. Transition risks are clearly more relevant. An abrupt adjustment of CO_2 prices, for example, could lead to severe losses in the financial market. In conjunction with other risks, this could lead to a destabilization of the financial market. Therefore an orderly transition to a low-carbon economy with clear long-term policy signals is desirable from a financial market stability point of view. There are, however, further analysis and research needs, such as the concentration risks of individual actors and network effects, especially within the financial sector.

1 Introduction

1.1 Objective of the study

The current IPCC report (IPCC 2014) shows that a massive reduction of global greenhouse gas emissions is necessary to achieve the political goal set out in the Paris Agreement, limiting the average global warming to well below 2° Celsius in the long term, and to even target a limit of 1.5° Celsius (UNFCCC 2015). At the same time, there are an increasing number of studies suggesting that more and more extreme events occur as a result of climate change and the insured losses are increasing (GDV 2011b, Arent et al., 2014, Barthel and Neumayer, 2012)

In this study, the possible effects of climate change on the German financial market stability are analyzed in detail for the first time, and outstanding issues are presented. This study encompasses the analysis of the probability and the origin of climate risks for financial market stability. It focuses on specific transition risks, i.e. the possibility that investments in high-emission sectors (e.g. cement) or those with high emissions in the value chain (e.g. automotive) could suffer a massive drop in value in case of an abrupt CO_2 price increase. It also examines the development of specific risk securitisation and information requirements by investors with regard to climate change.

For this study, financial market stability is defined as the status of the financial system in which it fulfils its macroeconomic functions, e.g. the efficient allocation of financial resources, even in case of unforeseen events or stress situations (Deutsche Bundesbank 2015a). Climate change can result in a number of possible shocks and imbalances, e.g. in case of massive losses in value due to abrupt regulatory interventions (transition risks) or extreme natural disasters, which can lead to massive losses for the financial and insurance industry (physical risks). Such shocks can weaken the capability of the financial system to ensure an efficient allocation of financial resources.

South Pole Group and CSSP have prepared this report, jointly with the University of Hamburg, as internal academic expert and Munich Re as network partner. Furthermore, an advisory board, consisting of experts from the fields of natural sciences and economics as well as the financial and insurance industry, provided assistance for the study, including Potsdam Institute for Climate Impact Research (PIK), Frankfurt School of Finance and Management, Humboldt University in Berlin, the Climate Service Center Germany (GERICS) and Concordia Insurance (for detailed composition see **Error! Reference source not found.**).

1.2 Overview of the study and answered questions

This report is structured as follows:

- **Chapter 2** provides an **overview and classification of the climate risks**, a description of the possible impact on financial market stability and the **definitions** of financial market stability, periods of time, as well as probabilities used for this study.
- **Chapter 3** answers the following questions on **physical risks**: How likely is it that a risk to financial market stability could develop based on the current IPCC climate scenarios in Germany/Europe? To what extent could this happen, e.g. (a) indirectly through damage to the real economy affecting the financial sector, i.e. through unexpected depreciation of loans or (b) direct influences, e.g. insurance losses or operational risks in the financial market?
- **Chapter 4** answers the following questions on **transition risks**: If the global climate change goals are to be observed consistently (1.5-2°-Celsius-limit), can a large part of the oil, natural gas, and coal reserves still be exploited ("carbon bubble")? Or would a large part of the assets in the energy-intensive industries, but also in downstream industries suddenly become worthless ("stranded assets")? Given this scenario, would the threats to the stability of the financial market increase?

- **Chapter 5** answers the following questions on the **pricing of climate change**: What could be the means to properly factor in the risk arising from climate change, especially with regard to long-term investments? Which sectors, assets, and maturities are affected? How is the externalisation of disaster risks for insurers/reinsurers evolving through special securitizations? In which sectors, assets, and maturities may the climate change risks already be "reasonably" factored in?
- **Chapter 6** answers the following question: What **information** do investors need to be able to assess climate change risks adequately?
- **Chapter 7** draws **conclusions** from the study and makes initial recommendations to the Federal Ministry of Finance.

For chapters 3 to 6, in addition to the analysis of data and literature research, semi-structured expert interviews with investment managers, insurance companies, and sustainability managers in the financial sector have been conducted. A list of the consulted experts can be found in **Error! Reference source not found.**.

2 Overview of climate risks and financial market stability

2 Overview of climate risks and financial market stability

In this chapter, the climate risks are typologised, their possible impact on financial market stability schematically demonstrated, and financial market stability, maturity, as well as statements on probability, more precisely defined.

2.1 Typologisation of climate risks

There are different systematisations of climate risks, which, however, all share similar elements. The Portfolio Carbon Initiative (2015), an initiative led by the United Nations Environment Programme Finance Initiative (UNEP-FI) and the World Resources Institute (WRI), lists physical risks and carbon risks while focussing on the latter. The Bank of England (Prudential Regulation Authority 2015) pursues a similar classification, as well as an overview of climate risks for the financial markets of the University of Oslo (Hjort 2016).

This study is based on the classification of the Financial Stability Board (2015):

- **Physical risks** are direct physical influences on economic value chains (for example, damage to buildings and production facilities, reduced snowfall in tourism areas, changed agricultural productivity) caused by longer-term climate change and weather-related events, the intensity and frequency of which will increase as a result of climate change.
- **Transition risks** refer to risks that arise as a result of the transition to a low-carbon economy and lead to a revaluation of investments.

The investigation of liability risks, which are often mentioned separately, is not part of the study. They indicate the possibility that compensation claims will be placed on actors who are considered responsible for climate change. The materiality of such risks has not yet been investigated in detail, and therefore there is hardly any literature on which an investigation could be based. One of the reasons is that there are only a handful of cases at this time, which only allows a limited assessment of the magnitude and likelihood of liability risks (2° Investing Initiative 2013).[6]

Both risk types are referred to as climate risks in this report. In this context, risk is the evaluation of events according to their frequency and impact, as well as the potential deviation from a target value. The probability of the event can thus be quantified.

Moreover, physical risks and transition risks are interrelated. A negative correlation is, for example, possible – the stronger the policymakers intervene to mitigate climate change, which is associated with more comprehensive adjustments for emission-intensive industries and therefore transition risks, the lower the physical risks that are to be expected. This assumes that mitigation measures can be implemented without undesirable side effects. At the same time, a positive correlation is also conceivable – e.g. an extreme physical damage event could lead to sudden strong policy measures.

Physical risks are also influenced by uncertainties within climate research – with uncertainties regarding the extent of climate change, including the possibility of tipping points, as well as the effects of climate change and the adaptability of the economy, population, and ecosystems (IPCC, 2014). There is also uncertainty about the extent of the transition risks – they depend on various factors, such as the likelihood and extent of political action.

[6] The Sabin Center for Climate Change Law (Columbia Law School 2016) collects legal proceeding related to climate change.

The risk groups can be structured into the following sub-aspects: **physical risks** manifest in (1) acute extreme weather events, such as flooding, droughts, and hurricanes, and (2) chronic changes, such as increased average temperatures, changing precipitation patterns, and rising sea levels. A third aspect is (3) tipping points, which are points at which global warming leads to radical changes in the climate system which can over the long term can intensify extreme weather events as well as chronic changes. Both extreme events and chronic changes can lead to damage to the real economy (Arent et al., 2014). An example of a tipping point could be that, starting from a certain concentration of greenhouse gasses in the atmosphere, the Arctic ice cap or the Greenland ice will melt, resulting in the acceleration of climate change due to a change of the albedo.[7]

Transition risks include (1) legislation and environmental policy regulation on an international, European, national and sub-national level, which aim at mitigation of climate change. (2) Technology risks, such as the development of low-carbon technologies and their propagation. This includes changes in industry standards and production costs. One example is the emergence of renewable energies, which, by means of the merit-order effect[8], tend to push the cost-intensive gas power plants out of the market. (3) Changes in the sales market and the economy as a reaction and consequence of the transition to a low carbon economy. Examples include changes in demand for oil and gas and negative effects for the reputation of climate-damaging companies.

The assessment of climate risks depends largely on the observation period. Physical impacts of climate change are already occurring today but will become more and more important in the medium to long term[9], both due to the increased accumulation of greenhouse gasses in the atmosphere and the delaying effects of the world's oceans. Due to the natural variability of the climate, extreme events are often not clearly attributable to climate change; the attribution of massive changes to climate change should become easier in the long term due to the clearer difference to scenarios without climate change. Liability risks are seen in the context of physical risks and are therefore expected in the long run when the physical effects of climate change can be observed on a large scale[10]. The emergence of stronger transition risks is already expected within shorter time horizons, based on existing policy and policy signals on the part of the policymakers.

2.2 Classification of effects

Risks associated with climate change can affect financial market actors and thus the financial system through different channels. The classification of these effects is based on our own analyses and the work of Battiston et al. (2016).

The first sphere of effect is the one of primary effects, where a risk directly affects a company's business operations. Insurance is affected, for example, by direct physical risks, provided relevant contracts exist.

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[7] The albedo is a measure of the reflectivity of the light from reflecting surfaces, which is a measure of the brightness of a body. Water has a much lower albedo than snow and ice (Climate Service Center 2012). Therefore, melted ice in the form of water will absorb significantly more radiation.

[8] Merit-Order describes the practice of first using energy sources with the lowest marginal costs to satisfy demand. Renewable sources of energy generally have low marginal costs (an exception are e.g. biogas plants, which currently account for a small proportion of renewable sources of energy), since they do not need fuels to generate energy.Therefore, they are – if possible – used more for energy production.

[9] For a definition of time horizons see chapter 2.4.

[10] Liability risks are especially high when contracts exist in which companies commit themselves to pay the indirect costs of their products, or when laws hold companies responsible for environmental damage.

Secondary effects are the effects of climate change through the investment of financial institutions in companies/projects affected by climate change. They are therefore indirect effects. One example is the introduction of a CO_2 tax for the entire economy, which has a negative impact on the equity price of an emission-intensive company, in which an investor is invested.

Tertiary effects include all the effects that secondary effects (as, for example, a negative impact on the investments of a financial market participant) have on the investment of other financial institutions. This can occur through “market price channels” and “information channels”, as set out in a document published by the European Systemic Risk Board in 2016 (Clerc 2016).

Market price channels describe effects in which the change in the market price of an investment affects all actors with exposure to this investment. The study of the University of Zurich (Battiston et al., 2016) investigates the impact of the depreciation of equities of emission-intensive companies through market price channels.

Information channels describe the effect of transferring negative effects from one financial institution to another without the actual level of exposure playing a role in the process. It is an information spillover effect, e.g. Bank A loses significantly in value as it has to make high write-downs on its emission-intensive investments. Information channels can now have two effects: (1) Bank B is exposed to Bank A and therefore also loses value regardless of the level of its direct investment in CO_2-intensive companies or its solvency. (2) Bank C loses value without being exposed to Bank A. This may have different reasons. Bank C might have a similar business model or offer the same type of product. An example of this second effect is as follows: Bank A offers equity funds, just as Bank C does. Since Bank A has lost value, customers not only withdraw money from the equity funds of Bank A but equity funds in general and thus also from those of Bank C.[11]

These indirect effects, which are referred to as tertiary effects in this report, are critical for the growth of local and minor shocks to major systemic problems (Clerc 2016). It gets particularly problematic if systemically relevant financial market actors are affected. The exact effects depend on the network relationships between the actors, which develop dynamically.

The primary, secondary, and tertiary effects for physical and transition risks are shown in Table 2.

[11] This may be due to a number of reasons, such as a general perception of increased risk of equity funds due to a lack of transparency regarding the actual risks.

Table 2: Overview of impact channels of climate risks

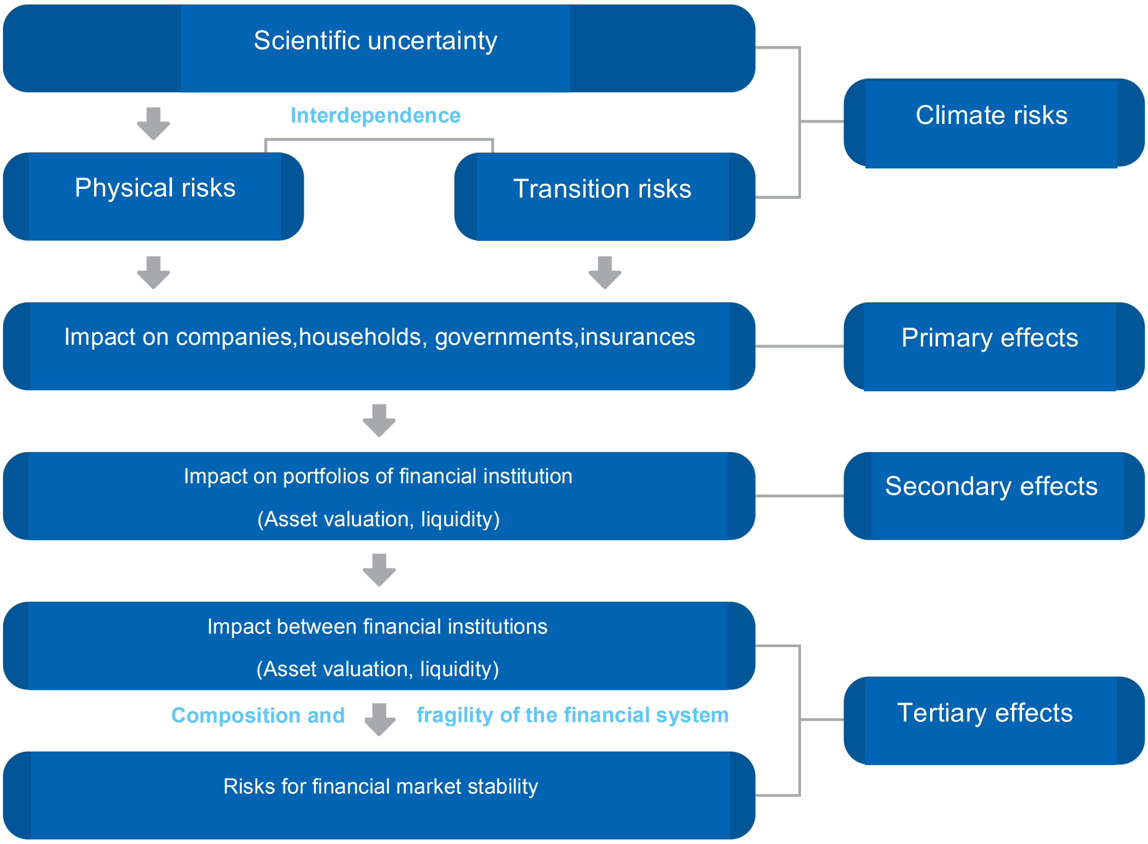
Risk type	Primary effect (sectors)	Secondary effect (portfolios)	Tertiary effect/ spillover between financial market participants
Physical risks	Insurance, agriculture, health sector, tourism, energy sector, water sector, infrastructure	All financial market participants depending on the exposure to industries affected by physical risks	All financial market participants, depending on the exposure to affected financial market participants
Transition risks	Emissions-intensive sectors	All financial market participants, depending on the exposure to emission-intensive industries (e.g. cement) and industries with high emissions in the value chain (e.g. automotive)	All financial market participants, depending on the exposure to affected financial market participants

Source: South Pole Group

The relationship between climate change and the different impact channels (primary, secondary and tertiary effects) is shown in Figure 3. Climate risks have an impact on the financial market through primary, secondary, and tertiary effects. Depending on the composition and fragility of the respective financial system, i.e. the gearing of individual institutions and the centrality of affected actors, this can lead to risks to financial market stability.

In the following chapters on physical and transition risks, we will focus on primary and secondary effects. However, tertiary effects are discussed in passing and are referred to in the conclusions.

Figure 3: Relationship between climate risks and impact channels



Source: South Pole Group, partly based on Bowen and Dietz (2016)

2.3 Definition of financial market stability and indicators of instability

For this study, financial market stability is defined as the state of the financial system in which it fulfils its macroeconomic functions. This mainly includes the efficient allocation of financial resources, even in case of unforeseen events or stress situations (Deutsche Bundesbank 2015a).

An efficient allocation of financial resources is not met, as long as the **social costs**[12] **of greenhouse gas emissions are not factored into the price of investments**. Inadequate pricing itself does not necessarily lead to instability of the financial system but can provide a basis for **shocks and imbalances** that call the stability of the financial market into question. Examples of such shocks are the bursting of a CO_2 bubble due to regulatory interventions (transition risks) or intensified and more severe weather damage that can reduce the insurability of climate risks and, in extreme cases, even solvency of individual companies (physical risks).

Insufficient factoring in of external costs as possible cause of financial market instability is examined under Chapter 5. However, the question of factoring in of external costs is not the primary focus of the study, as today's CO_2 market prices (approx. 5-10 EUR/t CO_2, see EEX (2016)) clearly show that the external costs of climate change (approx. 40-120 EUR/t CO_2, see

[12] External costs are economic costs that are not internalized in market prices.

UBA (2012b)) are not fully factored in[13]. However, the question of possible shocks and imbalances triggered by climate policy and physical climate risks has not been clarified yet and is therefore at the centre of this study.

This study assumes a shock or imbalance endangering financial market stability as soon as one or more of the following indicators exceed a certain threshold due to climate change.

The first indicator of this study for financial market instability is **increased volatility**. Volatility is a clear indicator of instability as significant price surges reflect the nervousness of the market. Volatility is also used by all central banks as an indicator of financial market instability (Gadanecz and Kaushik 2009). Typically, the volatility of individual equities is measured; this study, however, uses the VIX index, which is an aggregated index of expected volatility in the overall market. The financial market is considered volatile as soon as the VIX **reaches a value of more than 50**, a value the VIX reached on only 56 trading days since 1990 (CBOE, 2016). High short-term volatility could occur if governments announce massive unexpected climate-political measures, but weaken the statements within a few days to calm investors.

The second indicator is a **price slump** on the equity market. A shock scenario would be, for example, a loss of at least 7% in the financial market in one day due to a collapse of equities affected by climate risks. Such a day would rank among the 11 days with the biggest losses within the DAX since 1959 (Statista 2016) and the 20 days with the biggest losses within the Dow Jones in over 100 years (Wall Street Journal 2011). Massive price declines related to climate change could occur, for example, if unexpected massive regulatory interventions were announced to reduce CO_2 emissions.

The third indicator is **illiquidity of capital**. In the case of the insolvency of Lehman Brothers in 2008, liquidity of capital was no longer present as **interbank trading** no longer worked. Major divergences between supply and demand of equities can be an indicator of lack of liquidity as well. This could occur in the context of climate change if, for example, massive losses caused by secondary and tertiary effects lead to the illiquidity of an actor and the interbank trade collapses, since it is unclear which other actors are affected by the same risks and to what extent.

The fourth indicator is the **insolvency of systemically relevant actors**. If globally systemically relevant financial institutions (among German financial institutions only Deutsche Bank, see FSB (2015)), otherwise systemically relevant financial institutions (16 banks in Germany, see BaFin (2016)) or globally systemically relevant insurances (among German insurers only Allianz, see FSB (2015)) are no longer solvent due to climate shocks, the stability of the financial market as a whole is questioned.

2.4 Definition of maturities and probabilities

This study addresses short-term risks in an assessment up to the year 2020, medium-term risks for the period 2020 to 2030, and long-term risks for the period from 2030 onwards. In the statement on probabilities, this study uses the terminology of the IPCC (2014), see Table 3:

[13] It should be mentioned that the social costs of carbon (also called ‘economic costs’ or ‘external costs’) are very difficult to assess and are strongly influenced by the possibility of very unlikely, but extreme catastrophes („tail risks“). Particularly due to the climate change, such events are very difficult to assess and can, therefore, be more important for the consideration of external costs than the frequently discussed discount rate (Weitzman 2009).

Table 3: Definition of probabilities

Term	Corresponding probability
Virtually certain	99–100%
Extremely likely	95–100%
Very likely	90–100%
Likely	66–100%
About as likely as not	33–66%
Unlikely	0–33%
Very unlikely	0–10%
Extremely unlikely	0–5%
Exceptionally unlikely	0–1%

Source: IPCC (2014)

3 Physical effects and risks of climate change

3.1 Introduction

The impact of climate change on the European economy is evaluated by the IPCC in its fifth assessment report (Arent, et al., 2014, Kovats et al., 2014), as well as other studies (each cited if not IPCC sources)

- For most economic sectors, climate change will have a relatively minor direct impact compared to other factors, such as population growth or technological innovation.
- A stronger impact is expected in the following sectors: energy supply[14], water supply, transport systems, tourism, agriculture, infrastructure, and health sector.
- Climate change will affect the *insurance sector* through increased and more variable weather-related damage. In Germany in particular, insured weather-related damage has already increased by approx. 2.5% per year between 1980 and 2008 (it remains unclear to what extent this is due to climate change)[15] and for Europe and Germany, increased damage caused by snowstorms, hailstorms, and flooding has been predicted[16].
- Extreme natural catastrophes resulting from climate change can affect the *creditworthiness of sovereigns* [17].
- Climate change is likely to reduce the overall growth level and productivity, but the magnitude of the effect is not yet well understood. The *total* economic cost is expected to be approximately 0-3% of the GDP when the warming amounts to 2-3° (Arent, et al., 2014). In the case of stronger warming, which is to be expected today without future strong political intervention, the economic costs are likely to be significantly higher, even if the costs are very difficult to estimate due to the divergence from future compared to the current climate system (Stern 2013, OECD 2015).
- Europe is generally affected by climate change in similar sectors as other continents (Kovats, et al., 2014). Climate change will cause damage in the European economy through intensified heavy rainfall and rising sea levels as well as extreme temperatures. Especially in Southern Europe, the average availability of water will decrease. Climate change can, however, also have a positive economic impact in Northern Europe, e.g. in tourism, agriculture, and forestry (Kovats, et al., 2014).

More recent overview publications on climate change and its impact (World Bank 2014) largely confirm the results of the latest IPCC reports: the world is approaching a warming of up to 4° Celsius, and even in case of freezing today's greenhouse gas concentrations, average temperatures would raise by 1.5° Celsius (Cortekar and Groth 2014). The measures announced by governments under the Paris Climate Agreement will limit global warming to only about 2.7° Celsius (Gütschow et al., 2015). Therefore, the climate scenarios of the last IPCC report, which

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[14] Primarily cooling water (availability/temperature) and electricity distribution issues (conductivity and severe weather damage), as well as severe weather damage (Cortekar and Groth 2014). In the period of 2031-2050, the European electricity generation capacity could drop by 6-19% in the summer due to the increased cooling requirements (van Vliet, et al. 2012).

[15] Study conducted by Barthel and Neumeyer (2012) based on data from the NatCatService of Munich Re. Their model controls for population and economic growth as well as for changes in insurance coverage.

[16] In addition to the IPCC, the German Insurance Association as a whole expects these developments (GDV 2011b)

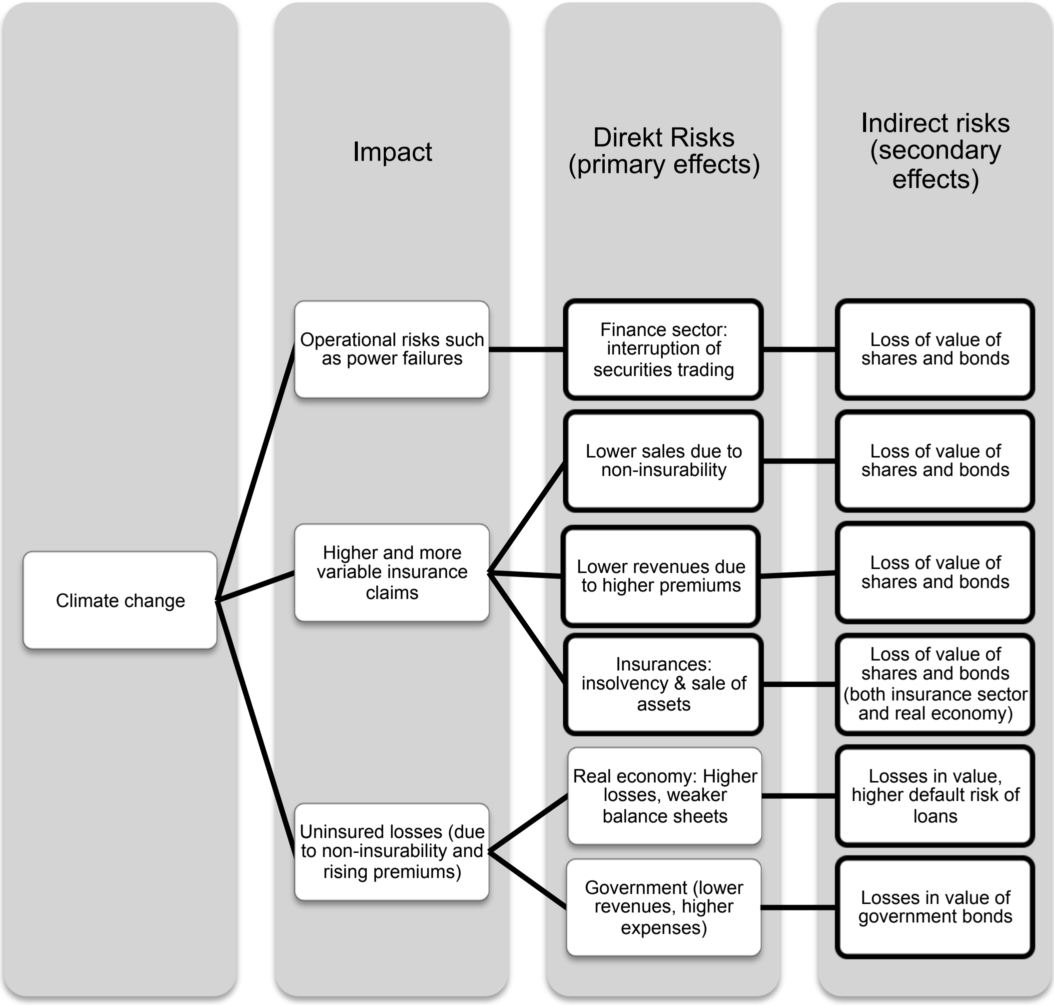
[17] In the case of Grenada and New Zealand, natural catastrophes (hurricane or earthquake) caused a downgrading of the country's creditworthiness due to short-term economic losses (Munich Re, 2013). Even if these natural catastrophes are only partly or not at all related to climate change, they show the possible effects of climate change on the creditworthiness due to extreme events.

are based on a warming of between 1° and 4° Celsius by 2100, are still a stable foundation for assessing the physical effects of climate change.

Two possible consequences of climate change become apparent from the literature that could pose risks to financial stability (see also Figure 4):

- **Direct physical risks (primary effects** *according to the classification in Chapter 2*) for financial stability such as operational risks in the financial sector and increased or difficult to predict losses for the insurance industry. If an extreme event occurs for which the insurances do not have sufficient financial reserves, they would have to raise capital and sell equipment on short notice, their creditworthiness could decrease and, in extreme cases, even their solvency may not any more be guaranteed. Such primary effects arise predominantly from extreme events such as floods, hail, windstorms, or cyclones (See Figure 4).
- **Indirect physical risks (secondary effects)** for financial stability through physical risks and damage to the real economy (mainly energy, water, agriculture, tourism, and healthcare sectors) that are not insured, and which affect the financial sector (e.g. changes in value and depreciation of assets after disastrous catastrophes, downgrade of creditworthiness, etc.). Indirect risks also exist in cases where the insurer can no longer fully cover the insured losses during an extreme event, has to execute massive asset sales, or increases the premiums due to climate change while no longer insuring certain risks, thus reducing the insurance coverage. Such secondary effects result from extreme events as well as due to chronic changes (temperature, sea level, etc.).

Figure 4: Assessment of possible impact of physical risks on the financial stability



Source: South Pole Group

Both direct and indirect influences on the financial market not only include **gradual, foreseeable effects of climate change** (chronic changes), which financial markets and the insurance industry can adjust to relatively well because of the better prognosticability and the gradual nature of the changes[18]. There are also risks of **abrupt, hard to predict effects of climate change on the financial market** (such as extreme floods or storms), which is the greatest threat to the insurance industry (Standard & Poor's 2014).

The following chapter is structured as follows: First, the direct physical risks for the financial market are discussed (in particular, insurance risks) and then the indirect risks of investments in companies that suffered damage. This is first discussed on a global level and then with reference to the German financial market. A conclusion chapter summarizes the findings.

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[18] An example of such expected, insurable influences is the increasing, foreseeable water scarcity in certain regions of the world. The finance and insurance industry can adapt to those changes: a tool has recently been developed to include water risks in the assessment of corporate bonds, see VfU(2016).

3.2 Physical risks (global level)

In the following, the global physical risks, i.e. the implications for the global financial market of potential physical events, are considered. There is little literature on the physical effects of climate change in the context of the financial market. The following summary is based in particular on the IPCC Assessment Report 2014 (Arent et al., 2014, Kovats et al., 2014), the PIK's Turn-Down-the-Heat publications for the World Bank (World Bank 2014), publications by regulators (Carney 2015, Prudential Regulation Authority 2015, Batten et al., 2016), the UBA study "Vulnerabilität Deutschlands gegenüber des Klimawandels" (Germany's Vulnerability to Climate Change, adelphi et al 2015), the BMBF project "Mainstreaming von Klimarisiken und -Chancen im Finanzsektor" (Mainstreaming of Climate Risks and Opportunities in the Financial Sector, Weaken et al., 2009), as well as studies on the impact of climate change on assets (Dietz et al., 2016, EIU 2015, Mercer 2015) and creditworthiness (Standard & Poor's 2015b, 2015c, 2015d). Both direct and indirect impact of climate change on the financial market through physical damage and changes are discussed, as well as the influence of nonlinearities[19] on the importance of physical risks.

For both direct and indirect effects, the predictability of damages is limited. Based on historical and statistical data, only limited prognoses of future effects on the stability of the financial market are possible, for several reasons: the future climate system will not look exactly like today, especially in case of warming beyond 3-4° Celsius (Stern 2013), then massive changes can occur in the financial sector in particular, see the financial crisis 2008/2009 (Germanwatch et al., 2009); and in general the adaptability of socio-economic systems is not easy to predict. Therefore, probabilities of certain risks to the financial market cannot be predicted only objectively on the basis of historical-statistical data. Subjective experts assessment, e.g. regarding future climate change, is also of importance (Germanwatch et al., 2009). Therefore, an exchange with a number of experts has taken place(list of experts consulted in Appendix II), in particular on questions regarding the management of physical risks by investors and the possibilities within the insurance industry to deal with the physical risks of climate change.

3.2.1 Direct influence (in particular on insurance companies)

3.2.1.1 Types of direct influences

Regarding the direct effects of climate change on the finance sector, the literature focuses on risks to the insurance industry due to a change in the insurance claims. The literature on other direct influences, e.g. 'operational risks' (physical damage to buildings of the finance sector[20] or damage to the communications infrastructure[21] used by the financial market) does not mention any significant risks to financial market stability due to such direct operational risks. The latest

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[19] Nonlinearity is a non-linear dependency between a dependent variable Y from an independent variable X, i.e. that in case of a proportional change of X, Y changes over- or under-proportionately.

[20] The UBA study "Vulnerabilität Deutschlands gegenüber dem Klimawandel" (Germany's Vulnerability to Climate Change, adelphi et al., 2015) does not consider the risks to the branches of the financial sector separately, but only integrated into the risks to the building park in general. Batten et al. (2016) mention the possibility of rapidly increasing provisioning requirements for liquidity in the event of the closure of bank branches and ATMs during major events but do not cite any empirical sources for this risk.

[21] While extreme events can destroy important communication-relevant infrastructures, in the case of Katrina, e.g. telephone lines, mobile communications antennae, and electricity infrastructure (Miller 2006), but it is currently unthinkable that climate change-related extreme events could affect the financial market communication in Europe/Germany over a wide area and/or a longer period of time. In the case of the "Power Black Out" in the USA and Canada in 2003, the financial markets were back to normal the next day (Bruch et al. 2011).

IPCC report (Arent et al., 2014) considers insurances in particular, as affected by climate change within the financial sector. Higher insurance claims and premiums are projected[22].

3.2.1.2 *Impact and adaptation strategies of insurance companies*

Through changed probabilities of losses from weather events, climate change affects both **primary insurance and reinsurance companies**. Changing weather patterns due to climate change and thus resulting in more frequent or higher damages are of great importance for insurers in various insurance sectors in the long term, mainly due to higher projected insurance losses (see Figure 5).

Figure 5: Long-term damage relevance of climate change for individual insurance sectors

Impact of climate change on individual insurance sectors - long-term (10-30 years)

Munich RE

	Flood/ storm surge	Severe weather/ flash flood	Heat/ drought	Cold/ frost
Property insurance (Private, commercial, industrial)	medium	high	medium	positive
Technical insurance (Construction, assembly)	high	high	low	positive
Transport insurance	medium	high	low	positive
Agricultural insurance (Harvest, animals, etc.)	medium	medium	high	positive
Car insurance	medium	high	low	positive
Aerospace insurance	low	medium	medium	no impact
Special risks (Event cancellation, etc.)	high	high	medium	high
Health insurance	low	low	medium	positive
Life insurance	low	low	medium	positive

Source: Munich Re (2016c)

The insurance industry has several **adaptation strategies** for the changing damage structure (see Table 4). In the case of increased damages in the multi-year-trend, **primary insurers** can increase insurance premiums, which is facilitated by the short-term contracts that are customary in the industry (often annual adjustment of premiums, see Arent, et al. 2014). In addition, insurers can reduce the insurance risks by forwarding information to insured parties. In case of longer-term increase of the variability of weather risk (i.e. greater probability that very extreme events occur), an increase of the risk capital (capital available to cover unexpected losses) may be advisable.

[22] So far, an impact of climate change cannot yet be clearly observed statistically. Insured losses have increased due to catastrophic natural disasters from the 1980s to the present day, inflation-adjusted from about 10 to 80 billion USD in the last decade (Prudential Regulation Authority 2015, Munich Re 2016b). However, this is generally explained in the literature by the general economic growth and the increased insured values (Botzen, van den Bergh, and Bouwer 2010). The impact of climate change has been used as an explanation only for certain events (e.g. super storm Sandy 2012, whose damage was increased as a result of rising sea levels (Prudential Regulation Authority 2015).

Since in case of large natural disasters, risk diversification is limited for local or regionally active primary insurers (Arent, et al. 2014), they buy reinsurance (or pursue other risk mitigation strategies)[23]. Changes in weather damages caused by climate change can lead to an increased need for reinsurance for primary insurances.

The **reinsurers** themselves have to increase their risk capital when there is a higher demand for reinsurance. Moreover, reinsurers can react to increased and more variable losses by adjusting reinsurance premiums (which in turn leads to premium increases for primary insurances), outsourcing insurance risks (e.g. catastrophe bonds) or forwarding more information on climate change to primary insurers.

For financial stability, it is particularly important that insurances and reinsurances adapt their risk capital in case of climate change: The regulation Solvency II (EC 2009) requires all insurance companies in the European Economic Area (EEA) to provide risk capital for annual losses (with reference to the overall insurance), which statistically only occur every 200 years. If the number of extreme events is statistically increasing due to climate change, then all insurers have to adjust their risk capital.

The adaptation measures discussed so far refer to cases, in which the level of damage and its variability is changing in a multi-year trend, and in which the insurance industry can rely on historical-statistical data. However, if several extreme events occur that statistically very rarely happen in less than one year, insurance companies can hardly adapt quickly and have to adapt reserves, sell assets, and possibly even raise capital (see last line in Table 4). Such an extreme situation can also occur without climate change, and due to the long-term effects of climate change it is not to be expected (and certainly impossible to prove) that the likelihood of such an extreme situation changes very quickly due to climate change.

Table 4: Possible adaptation strategies of primary insurers and reinsurers to different physical effects of climate change

Climate-induced changes	Primary insurers: Adjustment strategies	Reinsurers: Adjustment strategies
Observation of increased damages (trend)	Higher premiums, higher risk capital and reinsurance, information to customers	Higher premiums, higher risk capital, information to primary insurers
Observation of more variable damages (trend)	Higher risk capital and/or more reinsurance, higher premiums, information to customers	Higher risk capital, possibly higher premiums, information to primary insurers, issue of catastrophe bonds
Short-term occurrence of several extreme events, which are highly unlikely according to models (surprise effect)	Adjustment impossible, only emergency solutions: appropriation of reserves, sale of assets, short-term borrowing of capital	Adjustment impossible, only emergency solutions: appropriation of reserves, sale of assets, short-term borrowing of capital

Source: South Pole, based on Arent et al. (2014), Lloyd's (2015), Prudential Regulation Authority (2015)

The list of possibilities for adjustment to climate risks generally corresponds with common practice on climate risk management: According to interviews, all insurers adjust their models

[23] Changed probabilities and intensities of events can be included in the hazard section of probabilistic, exposure-based catastrophe models.

when historical statistical data shows a change in insurance losses (due to climate change or other reasons) and adjust premiums and their risk capital accordingly.

Larger insurers and reinsurers collect data on extreme events worldwide and also analyse possible scenarios for future climate change and its impact on the insurance industry. The derived findings are in part passed on to the smaller primary insurers. According to the expert interviews conducted, insurance companies are not only making regulatory necessary adjustments, but they have risk capital that goes far beyond the regulatory minimum, e.g. in case of Munich Re (2015) 1.75 times the annual losses (with reference the overall insurance) that statistically seen, only occur every 200 years.

Based on existing catastrophe models, the short-term contracts, the adjustment of the risk capital, and other means of risk management (diversification, risk transfer, adaptation of the scope of coverage, dissemination of information to insured parties) regulators (Prudential Regulation Authority 2015, Carney 2015), scientists (Bowen and Dietz 2016), as well as the interviewed experts generally consider the insurance industry well prepared to manage the physical risks of climate change in the short to medium term. The overview of the possibilities of adaptation shown here as well as the effective measures taken by the insurance industry according to expert interviews, also lead to this conclusion.

3.2.1.3 Possible challenges for the insurance industry (as of 2030)

In the long run (from 2030 onwards), the physical risks of climate change can nevertheless pose a challenge to the generally well-prepared insurance industry due to the following effects:

- The possible increasing volatility of weather and water availability will impose additional requirements on insurers when it comes to risk identification and measurement (Carney 2015, Prudential Regulation Authority 2015), e.g. an increase in the uncertainty that is already affecting the assessment of tail risks today (risks of very unlikely but extreme natural catastrophes), could increase with higher volatility of the weather.
- If the damage increases massively, certain insurance contracts could prove to no longer be worthwhile for both property and life insurance providers[24]. The consulted experts believe that insurance customers may no longer be willing to pay the required premiums. This would reduce the sales and profits of insurers.
- If insurances can no longer insure certain risks (e.g. certain buildings) due to very high risks and/or increase premiums massively, this could lead to regulatory or political interventions. This happened, for example, in the case of Flood Re, a compulsory reinsurance scheme in the UK where all building insurers co-finance the premiums of households with high flood risks (Carney 2015, Prudential Regulation Authority 2015). Political interventions can lead to the collapse of the insurance market in the long term as insurers are withdrawing from the market, as the example of the storm insurances in Florida has shown (Schenker et al. 2014).
- Effects that amplify damage: In the future, climate change could indirectly hit insurers through the real economy and global value chains. This happened, for example, in case of the floods in Thailand in 2011, which led to insurance claims (e.g. business interruption insurance) in the value chains of global companies (Fujita 2013).

These challenges can lead to three risks to the insurance industry, all of which are potentially relevant to the stability of the financial market, as they can lead to possible losses in value both for insurance companies and previously insured companies:

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[24] In our interviews with insurers, the area property was mentioned more often on the claims side. Life insurance seems to be more affected by climate change due to more long-term investments.

Non-insurability due to excessive uncertainty: Certain damages (e.g. damage to exposed buildings) could no longer be insured due to very high risks from natural catastrophes or uncertainties regarding the probability of loss, which would reduce the income of insurers. According to interviews, this climate change risk can be classified as very low in the short and medium term. This means that at least in the short and medium term it does not pose a relevant risk to financial market stability**.**

Loss of customers due to rising premiums: The adjustment of premiums is one of the most important resources for insurance companies to adapt to increased probability of loss due to climate change, and higher premiums would lead to tendentially fewer customers purchasing insurance contracts.

According to interviews, this risk of a loss of customers due to rising insurance premiums is clearly greater than that of non-insurability due to climate change. Box 1 in Chapter 3.3.2.1 exemplifies for hail insurance in Germany how a premium increase due to climate change could lead to a deeper relative insurance coverage.

Even if insurers should lose customers due to climate change, it is not to be expected that this could create a direct risk to the financial market stability as a result of severe losses in insurance companies, since the customer losses are hardly abrupt and only occur for specific insurance contracts.

Payment defaults and bankruptcies: In the case of an extreme event, some insurers could possibly no longer meet their obligations and might have to claim bankruptcy. This was the case 1992 after Hurricane Andrew in the USA (McChristian 2012). Due to climate change, such extreme events could become more likely, and the insurers would only perceive this with a delay. If insurers become insolvent, this could have an effect on the stability of the financial market through the loss of critical insurance services or disturbances in the market for securities lending (Batten et al. 2016).

A risk to financial stability due to the insolvency of insurance companies is very unlikely for several reasons. Firstly, according to Solvency II, on the level of the entire corporation, insurance companies are obliged to have risk capital for losses that occur statistically only every 200 years. For example, in the case of a correct estimation of the probabilities of risks, the probability of excessively low risk capital in any given institution should be significantly below 0.5% (100% divided by 200 years) per year.

Secondly, in case of the bankruptcy of one specific insurance company (microprudential view), , the financial market stability as a whole (macroprudential view) is still not at risk in most cases: It is unlikely that all insurers simultaneously file for bankruptcy, and Allianz is the only German insurer that is considered a globally systemically relevant institution (FSB 2015)[25].

Massive sale of assets: If insurance companies are forced to sell many investments quickly after extreme events to meet their obligations, this might not directly negatively impact the stability of the financial markets, but indirectly through the value of investments. A massive sale of insurance assets would push down the prices and thus adversely affect the balance sheets of banks and other financial institutions (Batten et al., 2016). This factor does not create a direct, but possibly an indirect risk to financial market stability.

3.2.1.4 Summary

Overall, it seems highly unlikely that the physical impact of climate change jeopardizes the stability of the financial markets in the short and medium term through direct risks to the insurance industry as long as it is assumed that the insurance industry can assess the probability of losses correctly.

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[25] For the German financial market, more insurances are systemically relevant .

However, through adjustments in the insurance industry (in particular through increase of premiums), climate change could lead to significant indirect risks to the financial sector. The next chapter discusses the possible significance of such indirect risks.

3.2.2 Indirect influence (secondary effects)

Indirect influences on financial market stability may occur, when investors invest in companies or countries affected by climate change

3.2.2.1 Types of indirect influences

In the case of indirect influences, investments are made by the financial industry in companies and assets, whose claims are not covered by insurance. Lack of insurance cover can have several reasons:

- **Lack of demand for insurance even without climate change**: Even today, insurance coverage is far from comprehensive, especially in low-income countries. While insurances covered about 37% of direct damages from natural disasters in rich countries in the years 2008-2011, only 4% were covered in middle-income countries, and even less in low-income countries (Wirtz et al. 2013). The German industry is almost 100% insured against the most important natural catastrophes (source: expert interviews).
- **Payment defaults:** In the case of extreme losses, certain insurance companies could no longer meet the contractual demands, which means the real economy (and possibly the state) would have to cover par of the damage itself. Based on the previous considerations, the likelihood of payment defaults in a particular insurance company is significantly lower than 0.5% per year as long as it is assumed that insurance companies are making correct assumptions with regard to the value-at-risk for their overall company[26].
- **Non-insurability**: Certain damages (e.g. certain buildings) could no longer be insurable due to very high risks or uncertainties in damage functions caused by climate change, which means that the real economy would have to cover the damage itself. According to interviews, at least in the short and medium term, this risk can be considered low (see above).
- **Rising premiums and thus lower insurance coverage:** In case of higher premiums, customers would tend to purchase less insurance, which would lead to significantly higher losses in the real economy in case of extreme events. This is probably the most likely scenario for dwindling insurance penetration due to climate change. If, for example, the premiums of certain insurance companies increase by 1% as a result of climate change, the relative insurance coverage could fall by 0.1-1% (see Box 1 in Chapter 3.3.2).

In the following, no distinction will be made as to which of these factors decreases the insurance coverage, but rather the consequences of this lack of insurance coverage for investors will be discussed. Based on the literature (Bansal and Ochoa 2011, Bansal et al., 2015, Standard & Poor's 2015b, 2015c, Hjort 2016), two ways will be discussed how uninsured losses due to climate change affect the financial market:

- Reduced value of investments (direct estimates and comparison with GDP);
- Downgrade of creditworthiness and depreciation on bonds and loans.

[26] The assumption of a correct assessment also refers to all risks of an insurance company, not only to the physical risks.

3.2.2.2 *Reduced value of investments in case of uninsured losses*

Climate change will reduce the market value of certain companies (Bansal and Ochoa 2011, Bansal et al., 2015) and increase that of others. If in the future insurers withdraw certain insurance coverage from certain companies or assets, or companies are no longer willing to pay premiums, this can reduce the value of certain assets (Carney 2015).

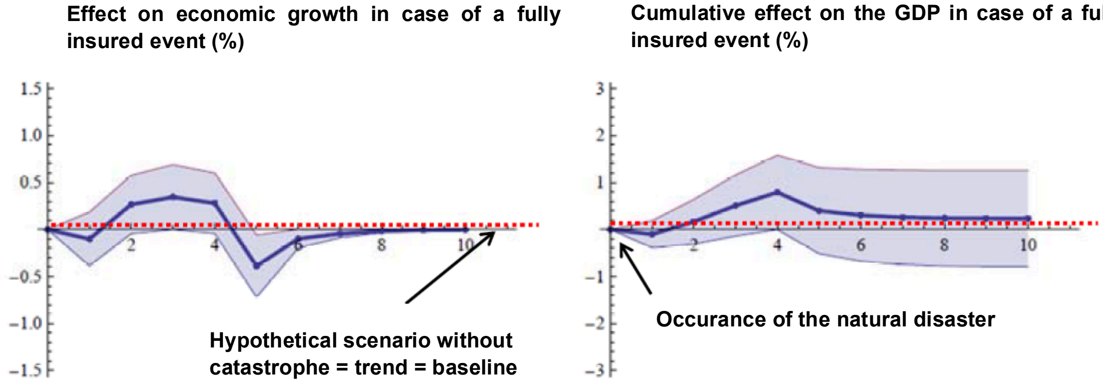
Dietz et al. (2016) estimate that without turning away from current emissions paths, global financial assets would be reduced by about 2% due to climate change. The uncertainty, however, is very high: in the 99% percentile of the probability distribution, 19% of all assets are already threatened. EIU (2015) assumes that a warming of 5° Celsius until 2100 will threaten about 10% of all assets. Covington and Thamotheram (2015) expect significant uncertainty in such estimates: depending on the robustness of economies (adjustment, regulation, and preventive measures), 1-20% of the assets could be in danger if the warming reaches about 4° Celsius by 2070. They assume completely diversified portfolios and no irreversible damage; if portfolios are not diversified, and certain losses are irreversible, the damage could be even higher.

Reduced value of investments along the gross domestic product (GDP): the market value of companies follows the long-term trend of the GDP, even if the correlation is not perfect (MSCI 2010). Therefore, the GDP offers an interesting approximation of how climate change could affect financial market assets. According to IPCC, the total economic costs of the physical impact of climate change is should be about 0-3% of **global GDP** in case 2° to 3°Celsius of global warming (Arent, et al. 2014); in case of more intense warming, the damage could be much higher. Typical economic models assume a damage of 5-10% of GDP for a temperature increase of 5° Celsius. However, these models are not very well suited to assess the damage caused by such a massive climate change, as they do not take into account certain climate risks since there is no historical data for such scenarios. This means they are likely to seriously underestimate the real damage (Stern 2013). Moreover, the costs in case of highly unlikely but very extreme catastrophes ("tail risks") would increase significantly (Weitzman 2009), the possibility of such events, however, is very difficult to estimate.

For all scenarios, the possibility that the effective net loss could be lower due to adaptation measures has to be taken into account[27]. Post-disaster measures can even increase the GDP in the short term to medium term through investments in new infrastructure (see Figure 6).

[27] According to the IPCC (Chambwera et al., 2014), the economic assessment of adaptation measures (at an aggregated level) is still at an early stage, but adaptation measures can reduce economic costs (since there is a number of measures that have more benefits than costs). A recent EU study finds less favourable cost-benefit ratios in effectively implemented adaptation measures, as theoretical studies often exclude transaction costs (ECONADAPT 2015).

Figure 6: Effect of a fully insured event on economic growth



Source: Munich Re (2013)

The damage to the GDP is very different from region to region (massively higher in Africa and South Asia) and could be higher than expected, as many models only account for one-year but not longer-term effects of economic shocks (Estrada, Tol, and Gay-García 2015).

Despite uncertainties, already the magnitude of the feared losses shows that the projected losses in value in case of uninsured damages hardly pose a threat to the financial market stability on a global level: If, in an extreme scenario, we were to expect a warming of 5° Celsius in the next 100 years and associated losses in value of 10% of the GDP, as well as 100% non-insurance of the additional damages as an extreme assumption, this would result in a reduction of assets and/or GDP of approximately 0.1% per year. The global GDP and thus the assets, however, should grow significantly stronger over the same period.

3.2.2.3 Downgrade of creditworthiness and depreciation of loans

According to Batten et al. (2016), non-insured losses not only result in lower investment values, but can also have a broader impact on the credit market: the risk of credit default increases due to weaker balance sheets of companies, households and states, and also, the amount of loans available in the future.

Creditworthiness of governments

In extreme cases, natural disasters caused by climate change could affect the creditworthiness of governments and companies, i.e. due to lower value added and higher government or operating debt to cover the damage. In the case of Grenada and New Zealand, certain natural catastrophes (hurricane or earthquake) have resulted in a downgrade of creditworthiness in the past (Munich Re 2013). Even if these natural catastrophes are only partly or not at all related to climate change, they show the possible effects of climate change on creditworthiness due to extreme events.

According to research by Standard & Poor's (2015c, 2015d), creditworthiness of certain governments could be downgraded due to climate-related extreme events, but not to an extent that would be relevant for financial stability (several notches[28] even in case of OECD countries). According to Standard & Poor's (2015c), climate change exacerbates the downgrading of a country's creditworthiness as a result of 250-year extreme events[29] (floods and hurricanes) by 0.23 notches on average in case of developing and emerging countries, and by 0.04 notches in

[28] AAA, AA+, AA, AA-, A+, A, A-, BBB+, BBB, etc. are considered as the main rating scale of creditworthiness. A downgrade by one notch e.g. is a change from AA+ to AA or A- to BBB+.
[29] 250-year extreme events are weather events, which occur in this intensity only every 250 years.

case of industrialised countries. In extreme cases, climate change can lead to a downgrading of creditworthiness by 1.8 notches (like in Thailand in case of a 250-year flood) and to an increase in national debt by up to 42% of the GDP (like in Barbados and a 250-year storm).

It should be noted that many of these extreme events can lead to a downgrade of more than 4 notches (e.g. Fiji, Barbados, and Bahamas in the case of a tropical storm) even without climate change. In the case of Western Europe, the downgrade of creditworthiness due to 250-year floods is between 0.08 (Germany, France) and 0.47 (Netherlands), and the additional downgrade due to climate change is even lower, between 0.01 (Germany, France) and 0.05 (Netherlands). Winter storms have a less strong impact (Standard & Poor's 2015c). Even though the research conducted by Standard & Poor's (2015c) is subject to the same uncertainties as general forecasts in connection with climate change, the magnitude (0.04 notches in case of industrialised countries, which are the relevant countries for financial market in Europe) shows that there is hardly any risk to financial market stability.

According to an expert interview, even the downgrade of a major industrialised country by one notch would not pose any major threat to financial stability.

Creditworthiness of companies

Climate risks may affect not only the creditworthiness of states but also the one of companies. On the one hand, the country-specific creditworthiness also affects the creditworthiness of companies. On the other hand, natural catastrophes can also threaten the creditworthiness of companies directly through non-insured losses.

According to Standard & Poor's (2015b), environmental and climate events have led to downgrading of companies 19 times so far, e.g. the US energy company Energy X was downgraded due to a higher probability of hurricanes and storms in the Gulf of Mexico. While downgrades due to natural catastrophes have been very rare in the past, climate change could lead to higher risks for the creditworthiness of firms (Standard & Poor's 2015b) through more frequent and exacerbated occurrence of extreme events, combined with increased global interdependence.

Higher default risk of loans

In most cases, a downgrade of creditworthiness does not result in a payment default of interest or the nominal value, but it certainly means a higher default risk. In case of higher default risks of loans (due to weaker balance sheets), banks tend to lend less credit (Batten et al., 2016) or charge a higher risk premium exacerbating a possibly already critical situation.

Due to a number of factors, the risk of financial stability being threatened by uninsured losses and the consequences for the credit market appears to be very low in the short and medium term. Firstly, a large proportion of affected companies are coverage by insurance in industrialised countries. Secondly, there are very few cases of a company's downgrade due to severe weather events. Thirdly, in case of extreme events, national states often cover part of the uninsured losses, and therefore, even in case of increased insurance coverage (due to increased premiums, for example), the insolvency risk for firms and private households is low. Fourthly, there is an extremely low probability of a downgrade of the creditworthiness of states in industrialised countries (expected downgrading by 0.04 in an event with a probability of 0.4% per year), and therefore industrialised countries should be able to absorb the risks of credit losses if the political will to do so. Due to the uncertainty regarding political decisions, the risk to financial stability is not classified as extremely low, but at least very low (somewhat more likely).

3.2.2.4 Summary

Even when looking at secondary effects, i.e. investments in equities as well as corporate or government bonds issued by affected companies or states, climate change should only lead to a very low risk to the stability of the financial markets. However, today's considerations are usually based on a heating of a maximum of 2°-4°Celsius, while the risks intensify with increasing warming, especially since nonlinearities play a larger role.

3.2.3 Nonlinearity of physical risks

The previous considerations regarding physical risks assume relatively well predictable linear effects of climate change, implying that the physical risks would increase gradually as a result of global warming.

There are a number of nonlinearities when it comes to physical risks, however, that can have an impact on financial stability. A study conducted by the Potsdam Institute für Climate Impact Research (PIK) on behalf of the World Bank discusses possible nonlinear effects in social systems (such as financial markets, emigration waves), intercorrelated effects and cascades of impact (e.g. spillover from world region to other world regions through value chains).

The most obvious nonlinearity, however, is a probability of extreme events that increases disproportionately with steady heating. A disproportionate amplification of extreme events could, i.a. occur, when there is a strong warming which leads to nonlinearities in the climate system itself. In recent years, climate scientists have increasingly discussed the possible occurrence of such tipping points in the climate system (Lenton, et al., 2008).

A "tipping point is defined" as a critical threshold in the climate system (e.g. GHG concentration in the atmosphere), where a small disturbance can qualitatively change the overall status or the development of a system. Figure 7 shows possible tipping elements in the climate system, e.g. the melting of the Greenland Ice Sheet, which would lead to an exacerbating climate effect due to a lower albedo. However, it should be noted that tipping points are phenomena that have a time limit of decades. Therefore, tipping points do not lead to a changed occurrence of extreme events immediately, which will make it easier for the insurers to incorporate the changes in natural hazard modelling based on observations.

The possibility of nonlinearities makes the prediction of physical climate risks more difficult. However, expert interviews clearly showed that most financial market players are hardly concerned with such nonlinearities. In fact, already the *linear* effects of climate change are causing them difficulties. Many experts rely primarily on the studies of the insurance industry or assess whether companies are insured against catastrophe risks. The major German insurers and reinsurers are assessing long-term scenarios, even including nonlinearities due to tipping points, but consider them as a risk without a direct impact on their own business in the short to medium term[30].

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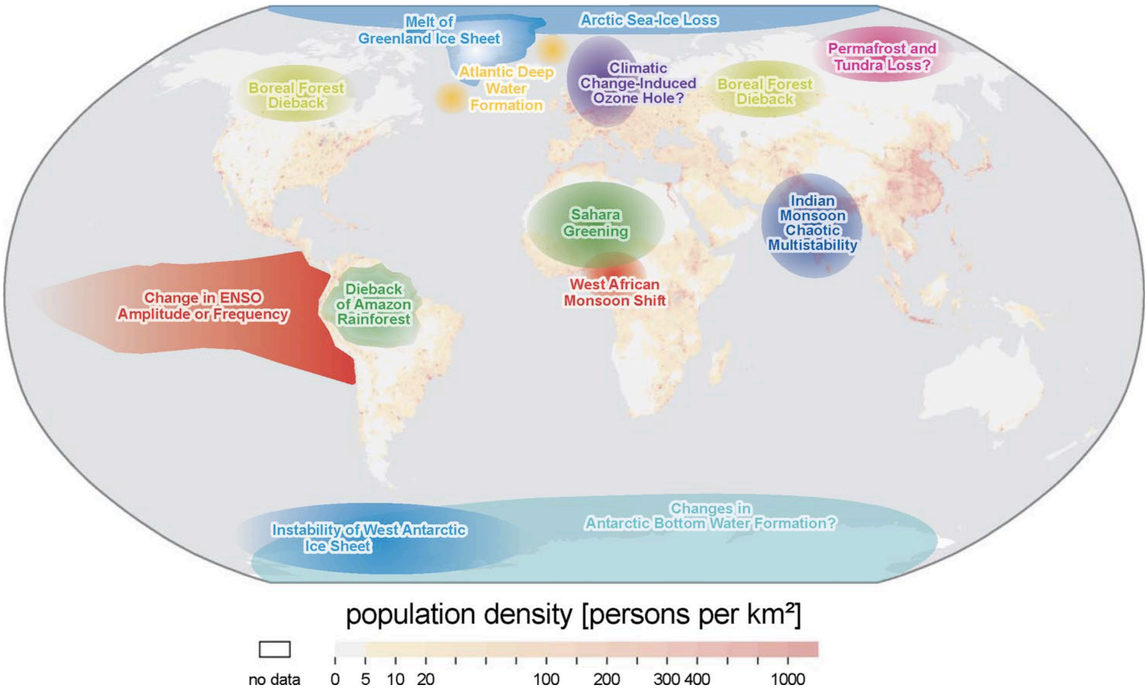
[30] The larger companies in the insurance market view the tipping points are not important in the short and medium term is in line with climate science, which even in the most conservative IPCC scenarios only expects a 2° warming around 2040 and a 3° warming around 2060. In case of moderate warming (2-4° Celsius), 43 surveyed climate scientists estimated the probability that at least one of the tipping points would occur at only 16% (conservative estimate), only in case of a warming of more than 4° Celcius they consider the probability to be 56% and more.

Figure 7: Map of politically relevant possible tipping points in the climate system



Source: Lenton, et al. (2008)

3.3 Physical risks for the financial market in Germany

3.3.1 Direct effects in Germany

For financial stability in Germany, primarily global effects are critical, since German financial market actors invest internationally and the major insurers insure predominantly risks in the USA and other European countries. However, there are a number of financial market actors who primarily operate in Germany, e.g. smaller primary insurers and regional banks. Even when it comes to loans as a major asset class, 60% of the German financial market is invested nationally (Deutsche Bundesbank 2016a). Therefore, the global view on physical risks is, hereby, supplemented by a German view.

For Germany too, there is no study that investigates the operational risks of climate change for the financial sector in depth. The issue was never raised by our interview partners when they were asked about the climate risks for their companies. Therefore, this section is limited to direct physical risks for the insurance industry.

3.3.1.1 Development of extreme events in Germany

In general, an increase in damages due to extreme events, which are influenced by climate change, is observed in Germany. This increase is statistically significant even if the analysis is controlled with regard to the growth of the GDP (gross domestic product), the population, the income per capita and the insurance penetration (Barthel and Neumayer 2012).

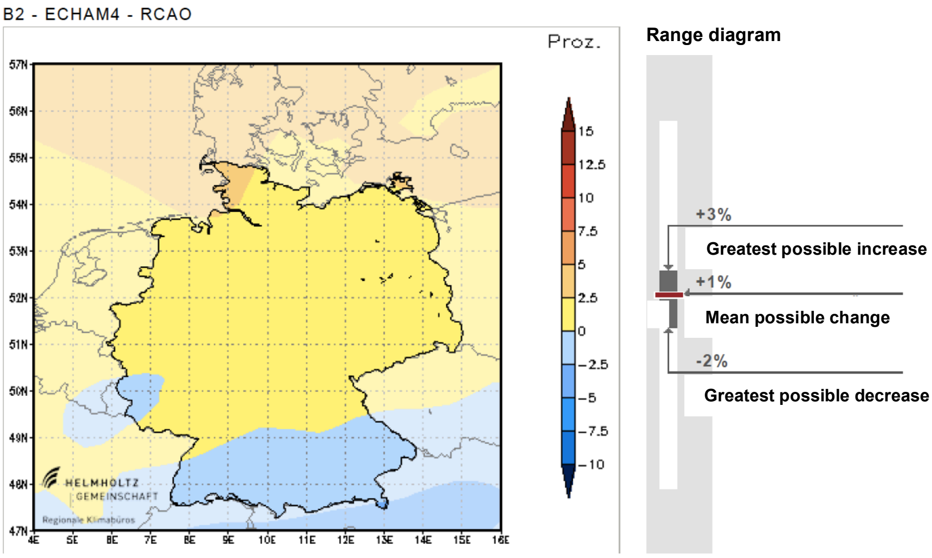
Til the end of the 21st century, the literature expects another increase in insurance losses in Germany caused by climate change, primarily as a result of winter storms, hailstorms, floods, and possible rising sea levels. Since all forecasts are based on various assumptions that are subject to high uncertainty, the range of the results of different scenarios is specified below:

- **Winter storms** (Held et al. 2013): The damage caused by winter storms in the moderate IPCC-scenario A1B[31] could increase by 6-35% (range of three scenarios) in the period 2011-2040, compared to the long-term average (1971-2010). For the period 2071-2100, the damage could even increase by 40-55% compared to the same base; here no adaptation measures are taken into account. The insurance sector assumes that these changes can be incorporated in existing insurance models (Held et al. 2013). The damage caused by winter storms is likely to occur more in north-west and south-west Germany (GDV 2011b). The increase in insured winter storm damages over the last 30 years is statistically significant, even when controlling for other important variables (Barthel and Neumayer 2012).
- **Hail/summer storms** (GDV 2011b): the damage could increase by 7% in the 10-year average for the period 2011-2040 compared to the long-term average (1984-2008); for the period 2041-2070, the damage could rise by as much as 28% on the same basis. The average loss rate (ratio of claims to the insured sum) of the strongest storm per year increases from 0.35‰ in the long-term mean from 1971-2000 to 0.85‰ for the period 2011-2040 and to over 1.4‰ for the period 2041-2070. What is especially relevant from a financial stability perspective: the likelihood of extreme events is growing significantly; a 50-year event will become a 10-year event. Especially in eastern Germany summer storms are likely to increase.
- **Floods** (GDV 2011a, GDV 2011b): The damage of EUR 460 million per year in the drainage basins of the five largest German rivers (Rhine, Ems, Weser, Elbe, and Danube) in the period 1961-2000 increase to EUR 1.44 billion per year in the most extreme scenario for the period 2011-2040 and up to EUR 1.51 billion per year in the period 2071-2100. The probability of extreme events also increases: a 50-year event will become a 25-year event. The damage could actually be even higher because the real CO_2 emissions are currently higher than the emissions assumed at this time, according to IPCC scenarios. In relative terms, the German economy is hardly affected by floods. Germany has a physical protection (e.g. embankments) against floods that occur only approximately every 100 years, and is thus among the 20% least exposed of all countries surveyed worldwide (Hallegatte et al., 2016).
- **Rise in sea level:** The rise in sea level is likely to lead to higher insurance losses along the North German coast, i.a. due to storm floods.

In these forecasts, it is important to note that there are major uncertainties in the models, e.g. wind force and precipitation increase or decrease depending on the model in Germany. See Figure 8.

[31] In recent years, effective CO_2 emissions have been significantly higher than the assumed emissions of scenario A1B, but the scenario could be compatible with the effective emissions in the long term due to the Paris agreement (email communication Hermann Held, June 27, 2016).

Figure 8: Potential mean change in mean wind speed - annual average by the end of the 21st century (2071-2100) compared to today (1961-1990)



Source: Helmholtz (2016)

3.3.1.1 Impact of extreme events in Germany on the insurance sector

Despite rising claims, insurers and reinsurers, both in interviews and studies (GDV 2011b), remain optimistic that they are prepared or can prepare for these damage scenarios. This is based not only on the possibility of a wide range of adaptation measures by the insurance industry (see Chapter 3.2), but also on the fact that the German insurance industry has been able to deal with insured losses for individual events as high as EUR 1.8 billion (Elbe flood in 2002) and EUR 2.4 billion (storm Kyrill in 2007) without major problems. Insurers have also learned from the 1990s (further development of models and risk assessment) when Hurricane Andrew caused USD 12.5 billion in damages in the USA. 11 insurers had to file for bankruptcy, even though far greater damages of USD 20-30 billion were considered possible beforehand and reinsurance was available.

All optimism on the part of the insurance industry aside, it has to be noted that it is still very difficult to assess the long-term situation until 2100 if the warming increases. Today’s models project extreme events up to 2100, although they are mostly based on data from the last 30 years (Lloyd’s 2015). Furthermore, even in the case of short-term forecasts, there is no certainty that the probability of loss can be correctly estimated on the basis of historical-statistical data.

3.3.1.2 Impact of damage events outside Germany

While the smaller insurance companies in Germany are strongly focused on the domestic market, larger primary insurers and reinsurers have an international focus. The interviewed experts see minor physical risks to German insurers doing international business for the following reasons. First, in the international business, similar adaptation strategies, such as information for insured persons, changes in premiums and risk capital as in domestic business are applied. Second, the internationally active German insurers are more concerned with climate change and changes in extreme events, i.a. through more complex models, data and studies (see, e.g., Munich Re 2013, Munich Re 2016b). Third, the international market is strongly oriented towards industrialised countries, and therefore, they have access to data on climate models and extreme events.

3.3.1.3 Summary

Assuming a correct assessment of physical risks by German insurers and reinsurers (as well as the other, business-related risks) and corresponding risk capital, which in Germany is even above the minimum legal requirements, the default risk of a particular insurance company is significantly less than 0.5% per year. Therefore, the direct risk for financial market stability is very low. With regards to keeping risks low, it is very important that the larger primary insurers and reinsurers in Germany are well informed about climate change, not only because of their own importance for the insurance market but also because they pass essential information on to smaller insurance companies.

3.3.2 Indirect impact for the German financial market

3.3.2.1 Reduced value of investments for non-insured losses

A greater risk to the financial market than direct risks is that some physical risks are not directly covered by the insurance industry and uninsured losses cause losses for financial investors. Only 28% of all German homeowners have natural hazard insurance (Elementarschadenversicherung), which leads to risks for real estate investors. Farmers are mostly insured against hail, but often not against other natural catastrophes (GDV 2011b). An increase in the insurance coverage is not a problem from the insurers' point of view, e.g. 98.5% of all buildings could easily be insured against flooding today (GDV 2011b).

Among German corporations, the relevant insurance coverage is close to 100% according to expert interviews, but the projected higher claims due to climate change are likely to lead to higher premiums, which could reduce the share of insured losses (see Box 1). As a result, the German financial market could be confronted with increased depreciation or losses in value of equities due to uninsured severe weather damage in the future.

Box 1: Potential changes in relative insurance coverage in case of rising premiums

An example will illustrate how the relative insurance coverage could develop in the event of rising premiums due to climate change. According to GDV (2011b), studies from hail and summer thunderstorms are, in the period 2011-2040, 7% more likely to cause damages compared to the long-term average. This could increase insurance premiums by 7%[32].

Cabas et al. (2008) noted in the case of Canada that an increase in insurance premiums for crop failures by 1% leads to a 0.3-0.4% lower demand for insurance. An overview by Grace et al. (2004) shows a lower decline in demand for crop insurance of 0.1-0.3% per 1% premium increase and a higher decline of up to 1% for other insurances such as building insurances. Taking these numbers as a range, an increase in the premiums for a hail insurance of 7% could lead to a decline in demand of about 1-7% for insurance in Germany. Furthermore, higher insurance premiums can lead to so-called adverse selection: policyholders with low risks terminate their contracts, while customers with high risks keep their contracts, thus increasing the risk within the customer base of insurances.

There are no studies on the value losses of German installations due to physical effects in the literature. In order to estimate the **magnitude of possible write-downs** or price decreases of equities, GDP forecasts are therefore considered, since GDP has a longer-term correlation with stock market values (see 3.2). Depending on the respective study, in Germany, climate change will cause **damage of approximately 0.1-0.6% of the German GDP by 2050** and 0.3-0.7% by 2080 (Hirschfeld, et al., 2015).

[32] This is a simplified assumption. The adjustment of the risk capital and the general market situation also play a role in determining premiums.

In Germany, too, the effective net losses should be lower due to adaptation measures. UBA (2012a) identifies eight adaptation measures with a positive cost-benefit ratio[33], which would achieve a net benefit of at least EUR 6 billion or 0.15% of the GDP in 2050. Subtracting these adaptation benefits of 0.15% of the GDP in 2050 from the maximum damage of about 0.6% of the German GDP in 2050, a **maximum net loss of 0.45% of German GDP in 2050** should occur.

In case of a maximum net loss of 0.45% of the German GDP in 2050 and (the extreme assumption) of full transferability to the domestic financial market, stock market values should fall by a maximum of 0.013% per year on average by 2050 due to climate change in Germany[34]. Thus, the physical impact of climate change on the German GDP development poses a very low risk to financial market stability.

3.3.2.2 Risks resulting from global interdependence

Further risks arise from the global interdependence of the German economy, i.a. through investments of the financial sector, damages in the supply chains, and in sales markets. If, as a result of climate change, the GDP fell by 2-3% (see previous chapter), for example, it is likely to have an impact on the German financial market. Due to climate change in sales markets, German exports could drop by 1.3-3.6% by 2050 (Schenker 2013). The influence of climate change on the supply chains of German companies has not yet been investigated.

Using the example of large floods in Thailand, Fujita (2013) demonstrates that such events can have an influence on the value chains of international companies. Wenz and Levermann (2016) argue that the international interdependence of value chains has increased over the past 20 years and that future climate damage can, therefore, be exacerbated through international trade. Therefore, in an extreme scenario of maximum international interdependence of the German financial and real economy, losses of up to 3-4% by 2050 can occur in the German financial market, in line with the losses in German exports and global GDP. **Depending on the international nature of the investment, asset values in Germany can, as a result, fall by a maximum of 0.01% to 0.1% per year by 2050.** Even these values represent a very low risk in the financial market stability compared to normal price fluctuations on the stock market of 5-10% per day.

The financial sector itself can further minimize this risk by implementing its own adaptation measures and promoting measures in the real economy. The Germany Insurance Association (Gesamtverband der Deutschen Versicherungswirtschaft*,* GDV 2011b), for example, proposes its own measures in the insurance sector (cooperation with the Climate Service Center regarding research, broader range of insurance, campaigns with federal states for higher rates of natural hazard insurance coverage) and in the real economy (construction restrictions, flood retention areas, drainage systems, structural adjustments).

3.3.2.3 Downgrade of creditworthiness and depreciation of loans

For a majority of the German financial market actors, the risks of a possible downgrade of their assets is extremely low as most almost exclusively invest in investment grade countries and, according to Standard & Poor's (2015c), only one of these investment grade countries (Bermuda) has to fear downgrade of its creditworthiness due to a 250-year climate-related extreme event.

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[33] 0.01% is the annual loss for investments only in Germany and loss in value of 0.45% by 2050; 0.1% is the annual loss with complete dependency on export and 3.6% export losses by 2050. 3.6% would also be an extreme value for global GDP losses by 2050 (Arent, et al., 2014)

[34] The 0.45% by 2050 were divided by 34 years (difference between 2050 and 2016). This calculation also includes direct risks to the financial sector.

The insurance industry can serve as a case study for this low exposure of the German financial markert: three of the largest German insurers (Allianz, Generali, and Munich Re) state that they invest more than 95% of their debt investments in investment grade products[35]. Assuming that insurers' investments are split according to a country's GDP, significantly less than 0.01% of the investment grade debt portfolio should be affected by a downgrade due to climate-related 250-year extreme events.

There should also only be a very low risk to the financial stability in Germany from depreciation of loans or higher loan default risk after extreme events. The lending business is strongly focussed on Germany and Europe, the degree of insurance coverage in Germany is very high, and the German governments, whose creditworthiness is not in danger even in case of a 250-year extreme event, is traditionally setting up aid programs in the event of major natural catastrophes.

3.3.2.4 Summary

Although the physical risks to financial market stability in Germany are currently very low to extremely low in the short to medium term, it is important to note that in case of warming beyond 2-3° Celsius, uncertainties exist regarding a change in GDP (Stern 2013), extreme events (Weitzman 2009), and security policy implications. Theoretically, the damage in the long term up to 2100 could be very high, and it is not clear how the financial market will react to it[36]. It is clear that the indirect physical risks for the German financial sector are increasing with the level of international interdepedence (especially when it comes to relationships to developing and emerging countries).

3.4 Conclusions

Physical consequences of climate change, which materialise as weather events, present direct risks for the financial market in form of higher insurance claims for the insurance industry and, on the other hand, indirect risks of uninsured losses in corporate and government assets, in which the financial market is invested.

At least in the short and medium term, the insurance industry can adapt well, as insurance premiums can be adjusted on an annual basis and risk capital can be adapted continuously. However, with increasing damage due to climate change, certain risks for natural disasters could no longer be insured as premiums become too high. This increases the indirect risks to the financial market if certain companies cannot or do not want to insure themselves.

Indirect risks include non-insured losses or unpaid insurance claims in extreme cases, which may result in higher default risks of loans and the downgrading of the creditworthiness of governments or companies. In this context, it is particularly relevant that 250-year extreme events would not lead to a significant downgrade of creditworthiness in the EU, but in certain smaller countries with a lower GDP. However, this means more of a risk to financial stability in these countries and is less of a concern for Europe/Germany as these financial markets are hardly investing in bonds and equities of such countries. Also long-term, gradual effects of climate change on the German GDP, pose little risks to financial stability.

For several reasons, it is very unlikely that a direct risk to financial market stability in Germany or Europe could arise due to the physical impact of climate change in the short and medium term.

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[35] Such debt capital investments account for a large proportion of investments, approximately 85% of the market value of all assets for Munich Re by the end of 2015 (Munich Re 2015) and 86.4% for all primary insurers (GDV 2016a). In the case of the entire insurance industry, the proportion of investment grade debt capital investments is also higher than 90% (see expert interviews).

[36] Due to the possibility of extreme scenarios with self-reinforcing dynamics, whose pobability is very difficult to assess (Schellnhuber 2010), the political 2° limit has primarily a precautionary function.

These include guiding regulations for the insurance industry (solvency requirements), the adaptability of the insurance industry, and the relatively small financial impact compared to existing volatilities in the financial market. The risk capital of the insurers in Germany is even above the legal solvency requirements. The greatest risk is an absolute extreme case when, within a year, a series of statistically extremely unlikely events with high damage may occur (surprise effect), and the insurance industry then can no longer cover all the damages. However, such an extreme situation is also conceivable without climate change, and it is unlikely that the longer-term climate change leads to changed probabilities in such a short time.

Somewhat more likely (but overall still very unlikely) are indirect short-term and medium-term risks to the stability of financial markets due to uninsured losses. While payment defaults are extremely unlikely in the case of affected European governments, there may be losses and credit default risks for uninsured companies in the case of extreme events, and thus possible reduction of lending and more unfavourable lending conditions by banks. Climate change exacerbates this risk through a possible reduction in relative insurance penetration as a result of rising premiums and (less likely) the non-insurability of certain risks. The risk of affected companies is still considered extremely unlikely as governments often cover part of the uninsured losses in extreme events, and thus contribute to risk reduction. With the degree of international interdependence, the indirect physical risks for the German financial sector are increasing as the insurance coverage abroad, especially in developing countries and emerging markets, is much lower.

In the longer term, physical climate risks to financial stability can be expected to become higher, as climate change will intensify and significant implications, especially in case of warming beyond 2-3° Celsius (increased likelihood of unexpected extreme events, economic and security policy implications, and drastic reactions from financial markets to unexpected extreme events), cannot be ruled out.

4 Transition risks

The more rigorously the 2° Celsius limit is targeted, the greater the transition required by CO_2-intensive industries. A problem for financial stability, as described in Chapter 2, is that unexpected, massive regulatory interventions to reduce CO_2 emissions could lead to abrupt price drops. Naturally, the risks are also associated with opportunities. Within the scope of this study, however, the focus is on the assessment of the magnitude of transition risks for financial actors in Germany. Several recent developments underline the relevance of this perspective.

Firstly, at the COP21, 195 nations agreed on new climate goals – therefore, an overwhelming majority of states have agreed to the explicit goal of limiting global warming to well below 2° Celsius and to even target limiting warming to 1.5° Celsius. These global goals are intended to lead to radical climate measures on a national level and could lead to a massive transition of economies and enterprises: in case of a regulatory factoring in of the economic costs of CO_2 (40-120 EUR/tCO_2 in 2010 (UBA 2012b)), approximately 2-5% of the Germany GDP would be affected (see Chapter 5). From a general social perspective, a successful decoupling of emissions and economic development would have to be achieved. For financial market actors, the question is whether they are prepared for this transformation.

Secondly, the risks, which carbon-intensive investments can pose, are increasingly the focus of governments and regulators. In France, the *Law on Energy Transition* (Ministry of Ecology, Sustainable Development and Energy 2015) was adopted in August 2015, which obliges institutional investors to report their climate impact starting from the end of 2016. In Sweden, Per Bolund, the Minister for Financial Markets, argued in support of financial markets contributing to climate change mitigation (Bolund 2015). Dave Jones, Insurance Commissioner of California, goes a step further and asks the approximately 1,300 Californian insurance companies to disclose their investments in high-emission industries, including oil, gas, and coal. Furthermore, insurance companies are to consider a disinvestment of coal (California Department of Insurance, 2016). Civil society is also engaged in a divestment movement, driven e.g. by the non-governmental organization (NGO) 350.org, which calls for disinvestments of the oil, gas, and coal industries.[37]

From the perspective of financial market actors, two concepts are pivotal in the context of transition risks: the concept of financed emissions and so-called “stranded assets”. “Financed emissions” refers to the concept of allocating investors of companies, projects, and organizations with the pro rata share of their investment. Thus, if an investor is holding 10% of the market capitalization[38], they are associated with 10% of the annual emissions of the company as financed emissions. The concept of financed GHG emissions is the current way of capturing and reporting the GHG intensity and climate impact of investors.[39]

[37] In the context of disinvestments, there are increasing discussions about the fact that large-scale fossil fuel-based energy producers have in some cases also already built up large capacities for renewable energies. This aspect is often not taken into account in disinvestment decisions.

[38] Total market capitalization is used. This includes fixed holdings and free float. Free float what?

[39] At the time of the study, there are a number of initiatives for the unified and practicable measurement of climate impact of investments. The most comprehensive initiative is that of the think tank World Resources Institute (WRI) and the United Nations Environmental Program Finance Initiative (UNEP FI), which focuses on indirect (scope 3) greenhouse gas emissions from investors. At the same time, there is another working group dealing with risks. National initiatives in France around the Agence de l'Environnement et de la Maîtrise de l'Energie (ADEME) and in Germany around the Association for Corporate Management (VfU) have similar objectives. Initial results and recommendations are expected in mid-2016.

"Stranded assets" are defined as investments, which are subject to an unexpected devaluation due to unforeseen changes in regulations, the physical environment, social standards, or technology.[40] A coal-fired power plant, which can no longer be operated due to higher energy and emission efficiency criteria or becomes unprofitable due to high CO_2 prices, would be an example of such a "stranded asset". Since certain business practices are likely to run counter to low-carbon development in the future, such companies may be significantly overvalued. In this context, the concept of a "carbon bubble" has emerged. It refers to the idea that there is a possible systematic overvaluation of companies in fossil energy production (CarbonTracker, 2013)[41].

For this study, the following questions arise: (1) how is the German financial market invested in terms of emission intensity? (2) Which stranded asset risks are potentially present? (3) Which statements can be made about potential risks to financial market stability?

The approach in this chapter is as follows: based on a sample of the German equity fund market, first statements are made, in particular, with regard to exposure to the oil, gas and coal industry and other emission-intensive industries. This serves as a detailed illustration of the problem fields in terms of transition risks per industry. In a second step, the transferability of the results of the equity fund market to the entire financial market is discussed. The chapter concludes with a discussion of the analysis results with respect to possible statements on the stability of the financial market.

4.1 Sample equity fund market Germany

A sample of equity funds is used to quantify by way of example, in which oil, gas, and coal companies and downstream industries the fund assets are most heavily invested, and what GHG emissions are associated with these investments. Moreover, concrete examples of methods for the detection of transition risks are explained based on an analysis of the fossil reserves of companies as well as the capital investments of oil and gas corporations in potentially unprofitable projects.

The 100 largest equity funds (based on total fund size) approved for distribution in Germany are examined as a sample.[42] Since many of the largest funds approved for distribution in Germany are not issued by German capital management companies, these 100 funds have been supplemented by equity funds of capital management subsidiaries of systemically relevant German banks.[43]

For the association of investors with emissions, the Scope 1 and Scope 2[44] emissions of a company are allocated to the investor proportionally to their own share of equity[45]. This means that, for example, an investor who owns 10% of the market capital of a company is associated

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[40] The term "stranded assets" has been receiving increased attention, i.a. thanks to the organisation Carbon Tracker (Carbon Tacker Initiative, 2013). The University of Oxford has furthermore launched a dedicated "Stranded Asset Programme"

[41] a recently published paper in *Nature* (McGlade, 2015), it is argued that half of all gas and one-third of all oil reserves, as well as 80% of the coal reserves would have to remain in the soil to reach the 2° Celsius climate goal.

[42] A statistic, which percentage of the money comes from Germany, was not included due to lack in data availability.

[43] Such German banks were qualified as systemically relevant banks, which are under supervision of the ECB.

[44] Scope 1 is direct greenhouse gas emissions of a company, e.g. those caused by production processes. Scope 2 refers to indirect greenhouse gas emissions through energy consumption (electricity and heat). Scope 3 covers the remaining indirect greenhouse gas emissions. Examples are emissions along the supply chain, during product use, or business travel.

[45] Total market capitalization is used for this purpose.

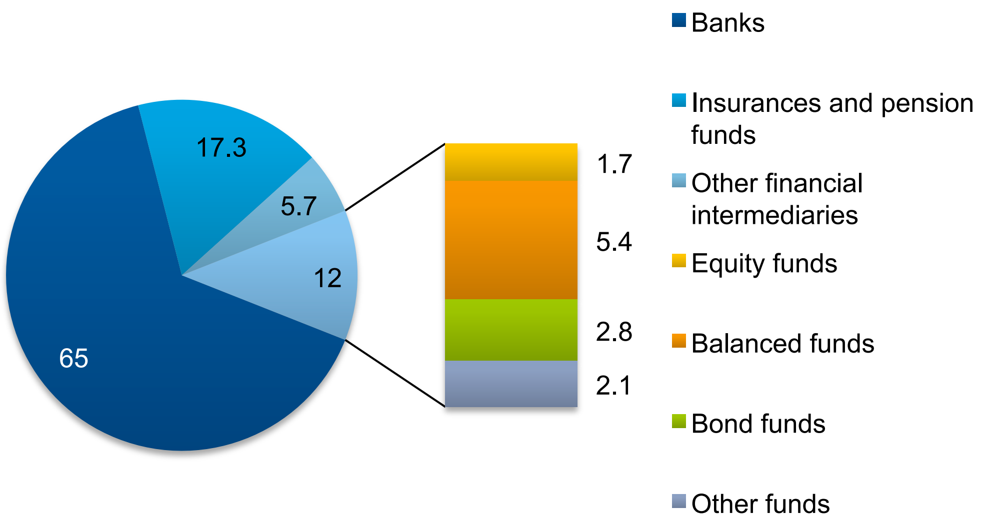
with 10% of the company's Scope 1 and Scope 2 emissions. These emissions are hereinafter referred to as "financed emissions". A detailed description of the sample, as well as the method used for the attribution of emissions per investment, is given in Appendix III.

Ideally, such an approach would also include Scope 3 emissions (GHG Protocol, 2004). However, this is not possible due to the often insufficient data quality. In the report, this perspective is therefore at least partially supplemented on a qualitative level, e.g. by considering the automotive industry in Chapters 4.1.3 and 4.2.2, which is important for the German economy and has high Scope 3 emissions.

4.1.1 Representative nature of the sample for the German financial market

The German financial market comprises EUR 13 trillion of assets. As shown in Figure 9, investment funds account for 12% of the financial market. EUR 246.5 billion of this amount is attributable to equity funds. They account for only 2% of the total financial market. The remaining investment funds are bond funds, balanced funds (consisting of shares and bonds) and other funds (e.g. real estate funds or umbrella funds).

Figure 9: Structure of the German financial market (shares of individual actors and investment fund types in %)



Source: Deutsche Bundesbank (2015a)[46]

The focus within the sample is on equities since equity capital is, in principle, more risky than debt. According to the creditor hierarchy, borrowed capital – and thus loans and bonds – are satisfied before equity capital.

The selection of the sample is also based on a number of technical considerations. Firstly, data on equity funds, in contrast to other asset classes and instruments, is available through

[46] The statistics on the general structure of the German financial sector are considered in the chapter "The macroeconomic and financial environment". The statistics on the investment funds in the chapter "Risks in the German shadow banking system".

specialized services. Secondly, the method of financed emissions, is an established approach, which in this form does not yet exist for other investment classes. Thirdly, the focus is on equity investments, since equities represent a stake in a company and thus an institutionalized responsibility as well as a risk attributable to the shareholder.

A consideration of other types of investment funds (bonds and balanced funds) and the investments of other financial market actors (banks, insurance companies, pension funds) is, of course, desirable despite the difficult data situation. Therefore, in chapter 4.2.1, the corporate bond funds market is exemplified. Chapter 4.2.2 discusses the transition risks of the German economy in general, as banks in particular often invest in domestic loans and this allows a rough assessment of their possible exposure to transition risks. The limitation of the sample is also addressed in Chapter 4.1.7, by means of a rough extrapolation of the transition risks for the entire financial market and a description of the associated challenges.

4.1.2 Exposure to oil, gas, and coal

The oil, gas, and coal sector is considered to be particularly exposed to transition risks[47]. This is i.a. because business models that are based on these raw materials do not have a low-carbon alternative. A company specializing in the extraction of oil may be able to reduce the emissions (e.g. methane flaring) of the extraction process, but the core business of the oil extraction will always run counter a 2° Celsius limit.

In order to meet the target of limiting global warming to below 2° Celsius, only about 20% of all presently known coal reserves, 50% of gas reserves, and 33% of oil reserves can be extracted and used (McGlade, 2015).

Overall, a good 5% of the investigated assets under management are invested in the oil and gas industry[48] (for an exact breakdown per sub-sector, please see Appendix III). These assets are mainly invested in companies with fossil reserves (also see the following chapter). This investment represents almost 20% of the emissions financed by the entire portfolio. The sectors "exploration & production" and "integrated oil & gas corporations" are of particular high emission intensity.

The coal sector accounts for only 0.02% of the portfolio under investigation. This corresponds to 38,000 tCO_2e or 0.08% of the financed emissions. This figure, however, does not accurately reflect the exposure to coal because many coal mining companies are classified as "general mining companies" because they mine other minerals as well. One example is Glencore, which belongs to the listed companies with the world's largest coal reserves. However, coal production accounts for only a small share of Glencore's total sales, making it one of the "general mining companies". In the following chapter, therefore, the analysis of the companies which have coal reserves serves as a supplementary perspective.

4.1.2.1 Exposure to the "Carbon Underground 200"

A discussion of the oil, gas and coal industries must take into account not only the current emissions but also analyse how many emissions these companies will be potentially responsible for in the future due to the greenhouse gasses embedded in their reserves. The reserves form

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[47]. There is a debate whether large energy companies can implement a successful transition. The impetus for this is the efforts made by Total to expand its activities in the field of renewable energies (Bloomberg 2015). To what extent this is sufficient for a transition remains controversial. In addition to the recent changes in the geopolitical environment (agreement to limit global warming to 1.5° Celsius), Stevens (2016), for example, also argues that certain assumptions underlying the current business model of large oil companies are disputable, irrespective of climate change, such as a steadily growing demand for oil.

[48] The definition of the sectors follows the Industry Classification Benchmark (ICB) (FTSE, 2012).

currently part of the company valuations but could be so-called "stranded assets" if exploitation is no longer worth considering due to international regulations or a low oil price.

The data of the ranking "Carbon Underground 200" is used (Fossil Free Indexes, 2015) for the analysis of the fossil reserves. This ranking of the 200 market-listed companies with the world's largest coal, gas, and oil reserves is based on the approach of Meinshausen (PIK - *Potsdam Institut für Klimafolgenforschung*) and is compiled by the organisation Fossil Free Indexes[49]. The data is based on fossil reserves, which are reported by the companies, and specialised industrial banks.

The ranking lists the 100 companies with the largest oil and gas reserves (*CU100 Oil and Gas*), and those with the largest coal reserves (*CU100 Coal*) in separate ranking lists. The reserves of the *CU100 Oil and Gas* comprise 97% of the oil reserves and 98% of the gas reserves of listed companies. The *CU100 Coal* corresponds to 98% of the proven and probable coal reserves of listed companies. Therefore, data from CU200 serves as an excellent proxy variable for global investments in fossil energy reserves. All 200 companies of the CU200 own a total of about 555 gigatons of potential CO_2 emissions, equivalent to 17 times the current annual CO_2 emissions from fossil fuels (IEA/OECD 2015).

Potential emissions are the emissions that would occur if all reserves were exploited and made usable for energy production and, at the same time, no carbon sequestration and storage were available or used. In contrast to the financed emissions, this is not a parameter that is measured annually. Rather, potential emissions refer to an indefinite period in the future, over which the reserves could be exploited. Financed potential emissions, therefore, refer to the potential emissions attributable to an investment under the "ownership" principle of an investment.

The following outlines, which companies of the CU200 the German equity fund market invests in.

CU100 Oil and Gas

The sample of the German equity fund market is invested in 82 of the 100 companies in the *CU100 Oil and Gas*. A list of all companies, their position in the ranking *CU100 Oil and Gas*, the amount invested in them, and the associated financed potential emissions are shown in Table 9 in Appendix III. In total, these 82 companies account for just under 4% of the portfolio of the examined equity funds and thus EUR 12.7 billion of investments within these funds. The financed potential emissions are 517 million tCO_2e[50]. This corresponds to almost 42% of the financed potential emissions of the portfolio (*CU100 Oil and Gas* and *CU100 Coal*), more than 10 times the emissions of nearly 50 million tCO_2e and more than 50% of Germany's annual emissions in 2014 (UBA, 2016b).

The examined portion of the German equity fund market is invested in all of the 10 companies with the largest oil and gas reserves, and thus in the 10 companies which have the largest potential total CO_2 emissions.

In total, the German stock market has a substantial exposure to *CU100 Oil and Gas* companies, not only in terms of financed potential emissions but also in terms of the invested amount, which accounts for just under 4% of the portfolio, as stated above. A reduction in company values, e.g. due to an increasing shift away from fossil fuels in the largest consumer markets, could have a significant impact on the return of the investment funds. Chapter 4.1.2.3 on potential stock price

[49] Fossil Free Indexes (FFI) creates benchmarks, tools, and research to support carbon-conscious investing. FFI first published the Carbon Underground 200 group in 2014: http://fossilfreeindexes.com/research/the-carbon-underground/

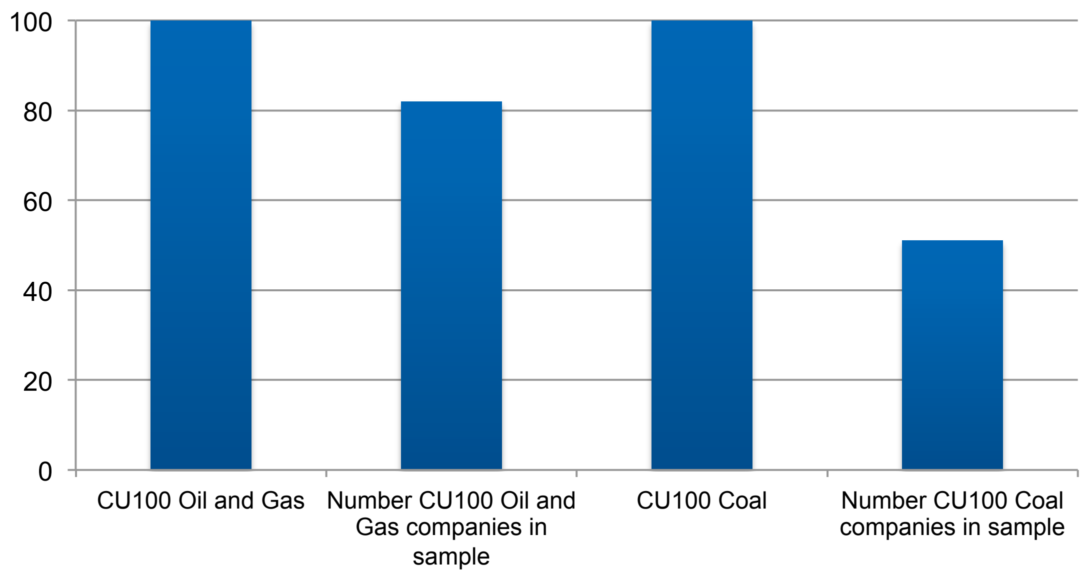
[50] In the calculation of the financed potential emissions, the potential emissions are allocated to the investor on a pro rata basis as regards the company's ownership of the company.

developments shows five examples of how the stock price would develop on the basis of different oil price scenarios triggered, for example, by regulations. It is also interesting to see the growing number of low-carbon stocks indices on the market, which are partly based on exclusion criteria, i.e. not investing in fossil fuels. Examples are the STOXX Low Carbon Footprint indices (STOXX, 2016b) and the MSCI ACWI ex Fossil Fuels (MSCI, 2015).

CU100 Coal

The examined sample of the German equity fund market is invested in 51 and thus about half of the 100 companies in the *CU100 Coal* (see Figure 10, and for details see Appendix III). In total, these companies account for 0.7% of the portfolio of the examined German equity funds, an invested amount of EUR 2.3 billion. The financed potential emissions amount to 727 million tCO_2. This corresponds to 58% of the financed potential emissions of the portfolio (*CU100 Oil and Gas* and *CU100 Coal*), almost 15 times the emissions of just under 50 million tCO_2e financed through the overall portfolio, and around 80% of the annual emissions of Germany.

Figure 10: Number of *CU100 Oil and Gas* and *CU100 Coal* companies in the sample equity fund market Germany



Source: South Pole Group based on Fossil Free Indexes

The sample of equity funds is invested in nine out of the 10 companies with the largest coal reserves and thus in the nine companies with the largest potential total emissions. The equity funds invested EUR 1.7 billion in the 10 companies which are associated with the highest financed potential emissions (a total of 656 million tCO_2).

In the grand total, the German stock market has a substantial exposure to companies in the *CU100 Coal* list. The 10 companies with the largest coal reserves in which the sample is invested, would be subject to potentially substantial losses in value if they were unable to use their reserves. At the same time, these companies account for significantly less than 1% of the investments of the equity funds in the sample. The risk of potential value adjustment is thus low for the equity fund market. However, this does not exclude a higher concentration of such investments in individual funds or, for example, pension funds and, therefore, the associated risks.

A report published in the run-up to COP21 examines, for example, the provisions regarding the coal investments of the largest global banks (Rainforest Action Network et al., 2015). Deutsche Bank was the only German institution to be analysed and, in addition to Credit Suisse, is lagging behind because of its comparatively low ambitions for its internal rules for coal investments. In general, as of December 2015, no conventional German bank has implemented a comprehensive scheme to exclude coal financing from its investments (Rainforest Action Network et al., 2015). Six smaller German banks[51] have excluded funding for coal-related activities under the Paris Pledge (Banktrack, 2015).

The current relevance of such risks is also reflected in the fact that in April 2016 Peabody Energy, the largest market-listed coal company in the world to date, had filed for bankruptcy (Miller 2016). At the same time, however, this example shows that such events do not necessarily lead to a shock to the financial system, even if individual investors have to accept high losses.

4.1.2.2 Exposure to high-risk capital investments

If global warming is to be limited to 2° Celsius, as indicated above, only one-fifth of today's declared reserves of market-listed oil and gas corporations could actually be exploited. Nevertheless, numerous corporations are still planning to invest in the exploitation of new reserves. These investments represent a "stranded asset" risk.

A total of 1.1 trillion USD of capital investments is planned for the exploitation of reserves by 2025, which would only be profitable at an oil price of 95 USD or higher (Carbon Tracker Initiative 2014). These are, in particular, cost-intensive conventional deposits, deposits in the deep sea, in the Arctic, and oil sands.

Major oil companies generally invest along large parts of the cost curve, i.e. investments that are already profitable at lower oil prices as well as those that are profitable only under the condition of high prices. Smaller companies often have a much higher percentage of their future capital expenditures in high-priced projects. Thus, they are exposed to a greater risk, while the major oil companies can potentially reduce their capital expenditure and at the same time can keep dividends stable.

The following is an analysis of the extent to which the German equity fund market is invested in companies which have planned large investments in potentially unprofitable deposits in terms of the absolute amount of their capital expenditures.

[51] The following German institutions have signed the Paris Pledge: Sparda-Bank München eG, Steyler Ethik Bank, Ethikbank, GLS Bank, Umweltbank, and ProCredit.

Table 5: Top 5 companies according to potentially risky CAPEX investments

Company	Risky investments (million USD)					
	Artic	Deep sea	Ultra deep sea	Oil sands	Others	Total
ROYAL DUTCH SHELL	1.42	189.42	148.41	242.20	11.39	**592.83**
BP PLC	83.72	141.18	309.78	50.87	2.92	**588.47**
TOTAL SA	0.41	140.17	219.45	97.76	0.47	**458.26**
STATOIL ASA	259.28	96.27	0.00	90.71	0.28	**446.54**
BG GROUP PLC	0.09	35.33	408.65	0.00	2.03	**446.09**
Total	**344.92**	**602.36**	**1,086.29**	**481.54**	**17.09**	**2,532.19**

Source: South Pole Group, based on data from Thomson Reuters and Carbon Tracker Initiative (2014)

Table 5 shows the pro rata capital investments of the German equity funds in reserves which become profitable only beyond an oil price of 80 USD (only investments by the five mineral oil companies in which the equity funds are most invested). Proportionately to the share of ownership of the mineral oil companies, these capital investments were allocated to the investments at risk in the equity fund market sample. If only investments of the equity funds in these five oil companies are considered, 2.5 billion USD (just under 1% of the portfolio) is high-risk, of which the majority is in deep-sea and ultra-deep-sea projects (almost 67%).

Thus, among others, the German stock market is financing the exploitation of reserves which could potentially lead to the exceedance of the emissions budget. At the same time – considering the current oil price of approximately 40 USD (as of end of February 2016) – the possibility exists that these reserves cannot be exploited profitably in the medium to long term.

4.1.2.3 Potential share price developments

For five oil companies, which the German equity fund market is the most heavily invested in, an analysis of the effects of changes in the oil price on their corporate values is to be analysed exemplarily. This is based on the consideration that a consequent government climate policy and associated regulatory interventions are reflected in demand and supply dynamics that would result in price changes.

The five examined companies were selected from the "integrated oil & gas corporations" sector and jointly account for around 1.8% of the examined assets. They account for 2.5 million tCO_2e of annually financed emissions. The companies are Royal Dutch Shell, BP, Total, Exxon, and Statoil[52]. A detailed listing of their portfolio weightings and annually financed emissions per

[52] According to the date of the portfolio composition of the examined equity funds (June 30, 2015) BG Group would have been examined, but the company has been taken over by Royal Dutch Shell in the meantime. Therefore Statoil is included in the analysis as a fifth company.

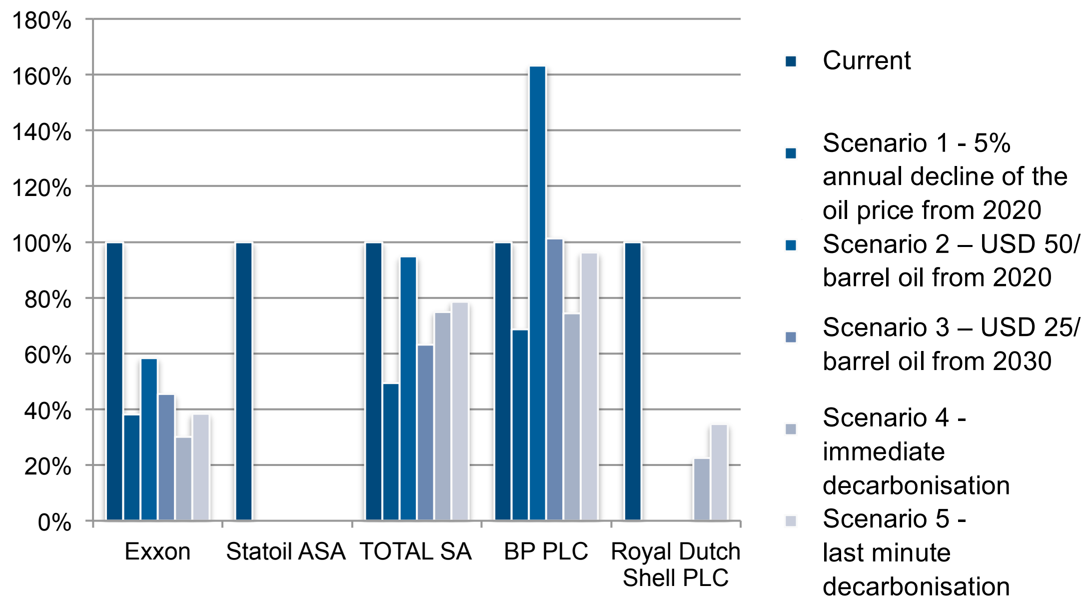
company can be found in Appendix III.

Within the scope of this study, the Bloomberg Carbon Risk Valuation Tool (Bloomberg 2013) is used to analyse the impact of different oil price scenarios. This allows for the analysis of the impact of different oil price and oil demand scenarios on the company valuation. The goal here is the estimation of an order of magnitude, not making a prediction.

The company value is assessed using the stock price for five different scenarios. These differ in two dimensions: Firstly, how abruptly oil prices change, and secondly when the change begins. The current company value serves as a benchmark for the results. A detailed overview of the scenarios can be found in Appendix III. A major assumption of the model is that the transition to a low-carbon economy is reflected in a lower oil demand and thus, a lower oil price. This further assumes that this price decline is not counteracted by reducing production.

As shown in Figure 11, the share price of all examined companies falls in all scenarios compared to their current value, except for BP in scenario 2. The results are thus comparable to a study by the HSBC (2013), which has calculated a loss of the share value of mineral oil companies between 40-60% based on standard valuation procedures in a low-carbon scenario. The dynamics for BP, which differs in scenario 2, is because BP has the lowest exploration, development, and production costs among all oil companies, which are below the assumed price of 50 USD per barrel in scenario 2.

Figure 11: Share price developments for various oil price scenarios (100% = no change)



Source: Bloomberg, analysis by South Pole Group

Whether and how these losses in value could materialize would largely depend on policy choices. The impact of these value adjustments on the stability of the financial market will also be determined by how quickly and abruptly they would occur. In addition, the impact on the financial market also depends on the extent to which the risks are passed on to downstream industries.

4.1.3 Other industries affected by transition risks

Limiting the warming to 2° Celsius means that the global emission level must have fallen by more than 50% by 2050, and a largely emission-neutral or even carbon-storing economy is to be achieved by 2100 at the latest (IPCC 2014). Thus, in addition to the mineral oil corporations, emission-intensive industries and those that produce emission-intensive products are subject to a transition to a low-carbon economy and therefore to transition risks.

Measured by their direct emission intensity (Scope 1 and 2), especially utilities, and the steel, cement, and aluminium industry, as well as aviation and the (trucking) forwarding industry (South Pole Group 2016) as well as industries which have an emission-intensive value-added chain or produce emission-intensive products, e.g. the automotive sector are affected by transition risks.

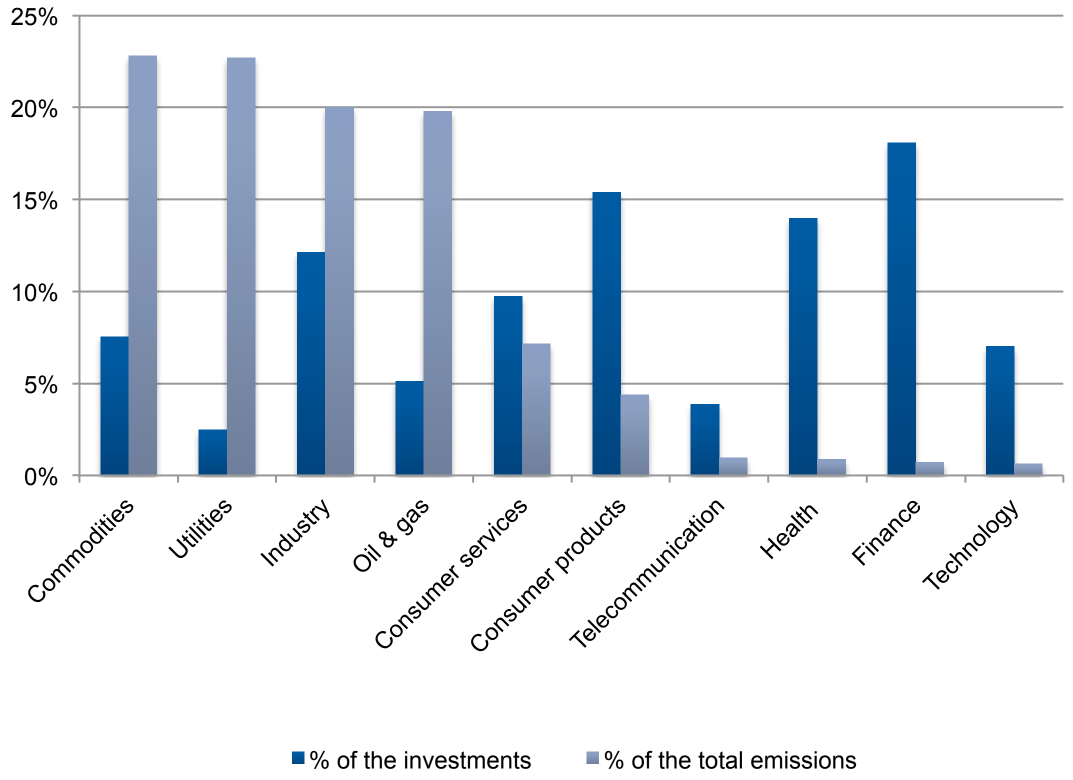
An estimate of which industry could be affected to which degree is currently only possible to a very limited extent, for several reasons. Firstly, it is not easy to estimate how quickly industries can switch to alternative, low-carbon business models. The current existence of such models serves as an indication, but the cost development and the emergence of new models are difficult to predict. Secondly, many products will cost more in a 2° economy (e.g. cement and steel), hence the price elasticity of demand for these products plays an important role in company evaluations. Thirdly, geography is important because different countries implement different regulations. The impact on the respective companies, therefore, also depends on the regulations in the countries in which their competitors are based and on the possible compensatory measures.

Within the scope of this study, the exposure of the German equity fund market to particularly carbon-intensive industries is examined in order to allow for an assessment of the magnitude of potential transition risks for investments in affected sectors.

Figure 12 shows that in addition to oil and gas, the sectors commodities, industry, and utilities (including utilities) significantly contribute to the financed emissions (Scope 1 and 2) compared to their portfolio weightings. A total of EUR 72 billion is invested in these three most energy-intensive sectors, respectively 22% of the portfolio. These investments amount to 31 million tCO_2e annually, which accounts for more than 65% of the emissions financed by the overall investments.[53] With around 12%, the industrial sector is the most heavily weighted of the most emission-intensive sectors. The supply sector is by far the most emission-intensive sector – in relation to its share of the portfolio, it is associated with most emissions. This is since the sector covers all major electricity producers and thus numerous coal and gas power plants.

[53] The commodities sector also includes the coal subsector.

Figure 12: Percent of investment and financed CO2 emissions per industry



Source: South Pole Group, Thomson Reuters

In addition to the aforementioned industries, the automotive sector should also be noted as a supplement. On the one hand, this is because it is characterized by high emissions for the operation of its products; and on the other hand because it represents an important industry in Germany with a share of around 14% of the DAX (Bloomberg, 2016). It is equal to 2% of the investments in the portfolio. When automotive suppliers and tyre manufacturers are factored in, the percentage of investments examined is just under 3%. These investments account for around 800,000 tCO_2e or 1.7% of the financed emissions (Scope 1 and 2). Thus, if only its direct emissions and not the emissions generated by the operation of the produced vehicles (Scope 3) are taken into account, the automotive sector is less emission-intensive than the average of the investments. The transition risks for the automotive sector are briefly discussed in Chapter 4.2.

4.1.4 Overall extent of transition risks

One way of assessing the transition risks of all investments in emission-intensive industries is the consideration of different price scenarios per tCO_2e and the resulting costs. In principle, various approaches can be used for this purpose. Economical costs are aimed at pricing all the externalities caused by emissions, including, for example, air pollution and resulting healthcare costs. Internal prices are the prices used by companies, which can be the result of various considerations such as current market prices, expected regulations, and externalities. Thirdly, in Europe, with the emissions trading system, a market price exists, which is determined by supply and demand.

Economic costs could serve as a benchmark for policy makers when introducing a future emission levy or a regulated CO_2 price for all sectors within the framework of an emissions trading system or increasing this price by, for example, setting price bands or reducing emission certificates. It remains unclear which actors would ultimately bear such costs - whether and to what extent, for example, consumers, companies themselves, fund managers, institutional investors, or private investors would have to do so.

In the context of this study, the economic cost approach is used to estimate possible CO_2 prices. It is based on the price recommended by the UBA (2012b) with climate change costs of 80 EUR/tCO_2e in 2010. This value is also used in further sources cited in this study, such as a study by the University of Hamburg together with Union Investment (Bassen, Busch, Lewandowski, & Sump, 2016). The author's own calculations are based on a price of 99 EUR/tCO_2e for the year 2014. This price is based on an interpolation of the price of 80 EUR/tCO_2e in 2010 (UBA, 2012b) interpolated to 2014 (based on the recommended prices for 2010 and 2030). A status quo analysis for the year 2014[54] is conducted.

This price scenario is applied to the oil and gas, commodities, industrial, and utilities sector for the examined sample of equity funds. It is assumed that investors in these equity funds must fully pay their emissions of 40.5 million tCO_2e in these sectors at a price of 99 EUR/tCO_2e. This would result in annual costs of EUR 4 billion for the concerned industries and represents 4.5% of the investments of EUR 89 billion in these sectors and 1.2% of the total investment of EUR 327 billion.

Assuming an expected return on investment of 8% in these industries, which is slightly below the average return on a DAX investment in the period from 2004 to 2013 (Deutsches Aktieninstitut 2014), it would drop by 4.8 percentage points to a 3.2% yield taking emissions into account.

4.2 Applicability to the entire financial sector

The German equity fund market, which serves as a sample, represents only one segment of the German financial market. A direct applicability of the analysis to other asset classes and actors is not easily possible. In this chapter, the above analysis is supplemented by three perspectives. Firstly, the applicability of the results of the sample to the entire investment fund market is discussed. Secondly, the transition risks of Germany are analysed to approximate the exposure of the financial sector, since many actors, such as banks, have a high exposure to the domestic market through loans (Deutsche Bundesbank 2016). Thirdly, an exemplary extrapolation to the entire German financial market is conducted.

4.2.1 Investment fund market

As described above, in addition to equity funds, the investment fund market in Germany consists mainly of bond funds and balanced funds. For this reason, a corporate bond fund is analysed as an example, in order to carry out an extrapolation of the results of the sample to the entire investment fund market in a second step.

4.2.1.1 Corporate bonds

For an exemplary study of investments in the corporate bond market, the iShares Core Europe Corporate Bond UCITS ETF was chosen. The Exchange Traded Fund[55] iShares Core Europe Corporate Bond UCITS seeks to replicate the Barclays Europe Corporate Bond Index (iShares 2016).

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[54] The equity fund composition as of June 31, 2015, was used to ensure a sample as complete as possible. This time lag is necessary since the fund composition is often published by the capital management companies with a time delay of (mostly) three to six months. For the emissions, the latest available data for the 2014 financial year was used.

[55] Exchange traded funds (ETFs) are traded on the exchange just like other securities.

This fund was selected for two reasons. Firstly, because of its focus on corporate bonds, for which, in contrast to government bonds, common methods for measuring the carbon footprint are available. The method is analogous to the financed emissions of shares, with the exception that the emissions are allocated to the outstanding borrowed capital.[56] Secondly, because the fund only considers bonds with an investment grade rating, i.e. bonds with a low risk.

Similar to the sample of the equity fund market, the sectors oil, gas, utilities, commodities, and industry are also the most emission-intensive within the corporate bond funds. They account for some 26% of the portfolio (compared to 27% for the equity fund market) and are associated with 94% of the financed emissions funded (compared to 85% for the equity fund market).

The oil and gas sector, and thus the most important industry affected by transition risks, is weighted at 4.5% in the portfolio, comparable to the sample for the equity fund market (5.1%). In comparison to the equity fund market, the examined fund weighs the utilities sector higher (8.3% to 2.5%) and through this sector alone, it is associated with 67.7% of the financed emissions. In total, it has an emission intensity of 277 tCO_2e per million EUR invested. It is, however, only one individual fund that is examined, and thus not a representative sample. Moreover, it can be argued that bonds are not as exposed to transition risks as equities are since claims of creditors are satisfied first.

A direct comparison of the analysis results of the sample for the corporate bond market and the equity fund market is, of course, not possible. However, at least parallels can be seen, such as the very similar overall portfolio allocation to low-intensity industries and the weighting of the oil and gas industry.

Moreover, previous studies on the effects of climate change on investment portfolios have shown that sectors are more relevant than asset classes (CISL 2015, Mercer 2015). This suggests that insights into the transition risks per industry are significant, irrespective of which investment class has been examined.

4.2.1.2 Extrapolation of the results for the investment fund market

Within the sample, EUR 327 billion of assets under management were examined. The annual emissions associated with these investments are 50 million tCO_2e. The statistic on equity fund of the Deutsche Bundesbank (2015), however, only includes investment funds that were launched in Germany or under German law (EUR 246.5 billion). This value is therefore different from the EUR 327 billion examined.

In order to extrapolate the emission intensity of the sample for the entire investment fund market, the emission intensity of the stock market sample is applied to the equity fund; for the bond funds, the emission intensity of the examined bond fund is used, and for the balanced funds the arithmetic mean of the two intensities (215 tCO_2e per million EUR invested). This is subject to the assumption that the sovereign bonds included in the bond funds have a similar intensity. A brief discussion of the methodological challenges involved takes place in Chapter 4.3.2.

According to this procedure, equity funds issued in Germany or under German law are associated with almost 38 million tCO_2e, bond funds with 112 million tCO_2e and balanced funds with 171 million tCO_2e. In total, these investments amount to EUR 1.5 trillion and are associated with 321 million tCO_2e.[57]

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[56] This means that an investor who owns 100% of a company's equity and 100% of its debt would be linked to 200% of Scope1 and Scope 2 emissions. This approach is useful from a risk perspective as the investor is exposed to the same ton of CO_2 emissions twice through two different investment instruments, which, as such, react differently. However, in case of an aggregate analysis of transition risks, the emissions would have to be split between equity and debt.

[57] Only equity, bond, and balanced funds were considered.

4.2.2 Global consideration of transition risks in Germany

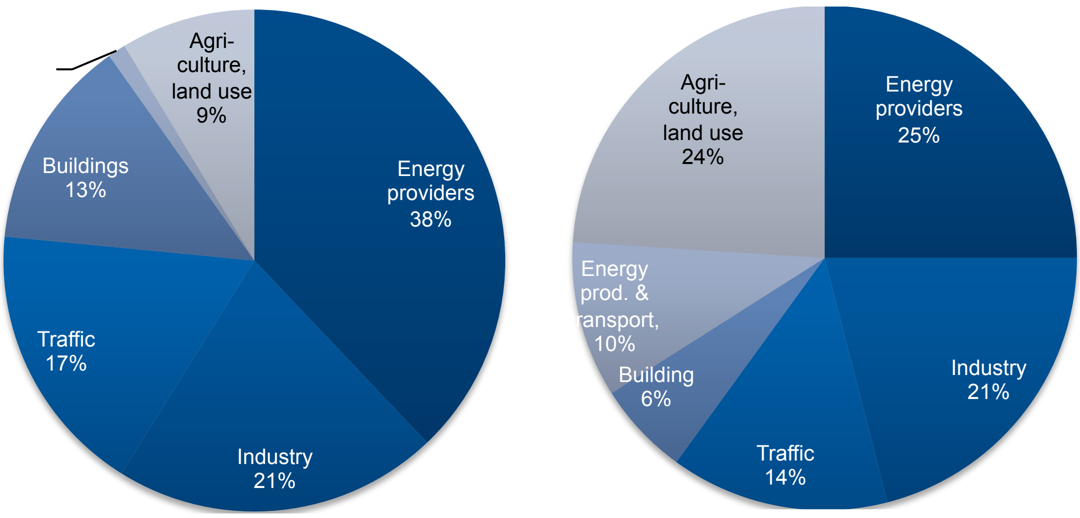
In order to approximate a global assessment of the exposure of the German financial sector regarding transition risks, the transition risks of Germany are analysed. This is useful, since many actors, e.g. banks via loans (Deutsche Bundesbank 2016a), have a high exposure to the domestic market. This is done through an exemplary analysis of the industrial composition of the German economy. The study is supplemented by two excursions: firstly, by German transition risks compared to other countries and secondly, by the effects of the transitional risks of other countries on Germany.

4.2.2.1 Industrial composition in Germany

In order to assess a country's transition risk, the question arises how much different industries contribute to the greenhouse gas emissions and how important certain industries are for a country, i.e. the share they have on the economic value creation. Domestic emissions and the domestic economy play a role for climate risks in the German financial market, as banks often extend a large proportion of their loans to banks and other actors in Germany (more than 60% of the total assets of German banks are attributable to actors in Germany itself (Deutsche Bundesbank 2016b)). If, therefore, a vulnerable industry is heavily represented in the credit portfolio of certain banks, the risk of systemic shocks is greater.

Utilities account for 38% of the greenhouse gas emissions in Germany, industry (chemicals and industrial goods) for 21%, and transport (road, aviation, and rail) for 17%. (See Figure 13, left). These three emission sources are also among the most important world-wide, although globally it is seen that agriculture, forestry, and energy exploitation/transport are more important. (See Figure 13, right).

Figure 13: Greenhouse gas emissions Germany 2014 (left) and worldwide 2010 (right)



Source: South Pole Group, based on UBA (2016a) for German & IPCC (2014) for global emissions

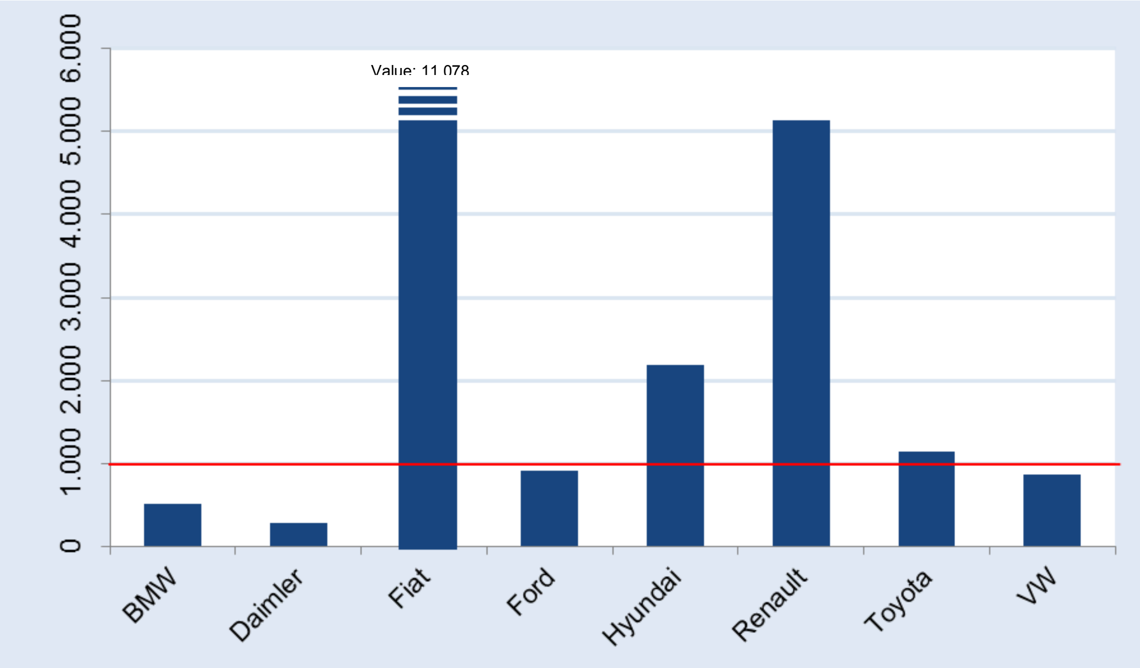
The DAX 30, the leading German stock index, is used as an approximation for the economic importance of various industries in Germany. Emission-intensive companies from the chemical (20%), industrial goods and services sector (13%), as well as automotive (14%) and utilities (3%) account for almost half of the index. If the DAX 30 can be assumed to be representative, emission-intensive industries play an important role in the German economy.[58] This is also

[58] According to Deutsche Börse, the index is representative (STOXX, 2016a). There are also other indices such as the CDAX, which cover a larger enterprise universe. The DAX 30 was selected as a reference point because of its publicity

reflected in the composition of the GDP, 26% of which was generated in the manufacturing sector (excluding construction industry) (Statistisches Bundesamt 2016a).

External climate costs of 80 EUR/tCO_2e in 2010 according to UBA (2012b)[59] can have a massive impact on the profitability of **automotive companies** (if they have to pay for those costs). German companies are, however, comparatively less severely affected (see Figure 14): The red line shows for which companies the internalisation of the costs of the emissions per EUR 1,000 profit would exceed said profit. However, it should be noted that BMW and Daimler have the highest CO_2 emissions per passenger kilometre of all the companies shown. They are therefore strongly exposed according to this relative metric. In addition, it is unclear who would bear these costs: whether car price would increase accordingly or if the costs would put pressure on the profits of automobile manufacturers.

Figure 14: Climate costs (Scope 3, utilization phase) automotive manufacturers per EUR 1,000 profit (year 2013)[60]



Source: Bassen et al. (2016)

The CDP sector report on this subject (CDP 2015a) provides an insight into the risks to the **chemical sector**. With BASF and Bayer, two of the chemical companies represented in the DAX 30, have been analysed according to seven different categories related to climate change. Both companies are placed in the upper third of the ranking list. While this cannot be seen as an absolute assessment of the risk, the report suggests that companies with higher rankings are likely to have fewer risks from a sustainability perspective than the other examined companies (CDP 2015a). The German chemical companies, therefore, appear to be better positioned overall in comparison to their competitors with regard to a transition to a low-carbon economy.

Utilities also play an important role. While they account for a comparatively small share of the DAX 30, E.ON and RWE are among the German companies with the largest emissions (CDP

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and common use.

[59] These costs seek to achieve a holistic assessment of the externalities of emissions.

[60] For the purpose of calculation, the emissions of the total useful life of the car (average kilometres travelled and caused emissions as well as production) were shown at a cost of 80 EUR/tCO_2.

2015b). Both companies, as well as the third-largest German utility ENBW, use significant amounts of coal for energy production and thus have a high exposure to costs that could result from a complete pricing of their emissions. If the CO_2 price of EUR 99, as assumed under this study is used, the EBIT of the three companies would decrease by an amount of 96% to over 200% (based on a linear calculation).

In Germany, there is also a high regional concentration of coal and mineral oil power stations. With 44 power stations, North-Rhine Westphalia[61] has by far the highest concentration, followed by Baden-Württemberg (21), Brandenburg (13), and Bavaria (11) (Bundesnetzagentur 2015). This means that well over half of the currently 149 fossil-fuelled power plants are located in just four federal states. The effects of having a price on CO_2 would thus have very different economic effects depending on the region.

Restrictively, it is self-evident that CO_2 prices only allow a first approximation of the assessment of transition risks. It is precisely the situation of the German utilities that shows that risk factors go far beyond CO_2 prices and must be seen in the regulatory and market context. For example, due to the currently low CO_2 prices, lignite plants are often more profitable than significantly less CO_2-intensive gas power plants (Morison 2016).

Emission-intensive industries thus play an important role on a regional (see coal and petrol power plants) and national level (see composition of the DAX 30 and GDP). German banks are mostly invested domestically. This leads to the conclusion that German banks thus hold substantial shares in emission-intensive companies in their balance sheets, and, therefore, could be exposed to transition risks that are relevant to secondary and tertiary effects. In fact, about 27% (more than EUR 350 billion) of loans from German banks to domestic enterprises and self-employed individuals are in sectors potentially affected by transition risks (Deutsche Bundesbank 2015b). These are actors in the sectors construction, transport, waste-management, energy supply, and trade and repair of motor vehicles.

Another effect to be taken into account is the correlations between the credit portfolios of different industries. A study by employees of the Deutsche Bundesbank, for example, stresses that effects on one sector can have an impact on the loans in related other sectors (Düllmann 2008). Here, too, secondary and tertiary effects could be expected.

4.2.2.2 Excursus: Real Estate

The exposure of financial market actors to real estate can be manifold. Financial market actors can

(1) Be invested in companies that own real estate;
(2) Invest in real estate companies (the real estate company Vonovia, for example, is represented in the DAX 30);
(3) Be invested in real estate as a separate asset class;
(4) Grant mortgages/loans themselves in connection with real estate (banks).

For an assessment of the magnitude of the potential impacts of climate change, an exemplary analysis of the loans granted by German banks for housing construction is carried out. Thus, case (4) is considered. An analysis of loans/mortgages in the housing sector is particularly interesting as these are often associated with financial crises (see Reinhart et al. (2008)).

The introduction of a CO_2 price could have a direct impact on the housing sector (higher oil and gas costs) and an indirect (higher electricity costs due to suppliers who have to pay dues). The

[61] The number includes power stations in operation as well as those classified as reserve power stations.

question arises how there additional costs, if borne entirely by borrowers, would compare to the interest rate burden, and what default risk can be derived from this.

German banks hold more than EUR 1.2 trillion of loans for housing construction (Deutsche Bundesbank 2016a). Assuming an average annual interest rate of 2.07% (Deutsche Bundesbank 2016c), annual interest payments amount to EUR 25.2 billion.

Based on average housing prices, the final energy consumption of the building stock in Germany, and the CO_2e emission factor for electricity consumption, emissions of almost 47 million tCO_2e associated with the loans were calculated (detailed calculations in Appendix III). Based on a CO2 price of 99 EUR/tCO2 (using the method described in Chapter 4.1) this results in annual costs of EUR 4.6 billion. This corresponds to 18.4% of the annual interest burden. This could potentially lead to a reduction in the solvency of certain borrowers.

The calculation is, of course, subject to a number of limitations, such as the global average values used. It is also assumed that borrowers themselves have to pay for the emissions of the living space financed by the credit.

4.2.2.3 Excursus: Transition risks of Germany compared to other countries

To analyse Germany's transition risks in comparison to other countries, (1) the respective composition of the economy and its exposure to carbon-intensive industries are examined, as well as (2) the relative emission intensity of Germany. This exemplary analysis is carried out by means of a comparison of the DAX 30 as a German leading index with the STOXX 600 as European benchmark index, and the S&P 500 as US benchmark index.[62] These indices represent the market-listed industries of their respective geographic economic areas by covering the respective largest companies.

A comparison of the indices shows that the three sectors of commodities, industry, and utilities play an important role in all three indices: their share in the DAX 30 is 37%, in the EURO STOXX600 25%, and the S&P500 17% (Bloomberg 2016)[63]. This suggests that emission-intensive industries are more important for Germany compared to the North American and the European economy as a whole and that Germany could be exposed to higher transition risks. While there is little exposure of the DAX to the oil and gas sector, industry has a comparatively high weight.

Furthermore, emission-intensive industries are an important component of German exports. Automobile and automotive parts, machines, and chemical products were the three most important German export goods with a total of EUR 459 billion (Statistisches Bundesamt 2015). This also indicates a trend towards a higher exposure of Germany to transition risks compared to other globally important economies.

On the other hand, Germany has reduced the emission intensity of the national economy by 57.5% between 1991 and 2014.

Measured per USD of the value added (GDP), Germany emitted about 0.2 kg of CO_2, which is on average about the same as the European Union and less than the USA with 0.3 kg CO_2 (World Bank, 2016a). The Federal Government's emission reduction targets also provide for a reduction of 80 to 95% of emissions by 2050 compared to 1990 levels (BMUB, 2014). Such a clear announcement of long-term goals and step-by-step implementation reduces the transition risks as changes can be anticipated by the companies and a gradual adjustment can take place.

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[62] These three indices have been selected because they are the benchmark indices of the respective country or region.

[63] The calculation is based on ETFs of the three indices, which replicate them.

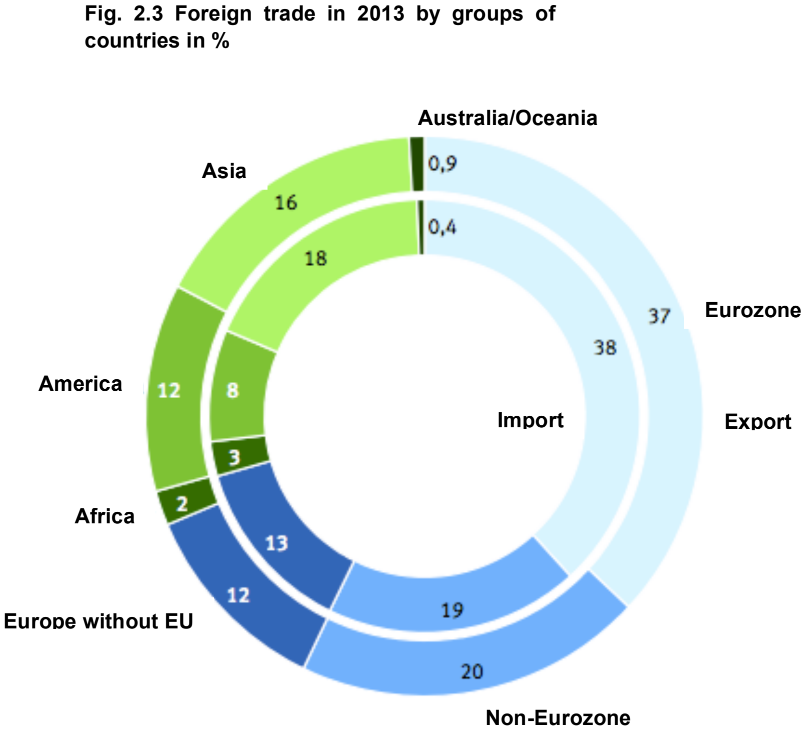
These considerations alone give no indication of the transition risk profile of Germany. A fundamental assessment of the transition risks should also consider the mitigation or adaptation potential of individual industries and companies. If, hypothetically, it were easier for all German car makers to implement a 1.5-2° Celsius compatible corporate strategy than for American ones, the transition risks for this sector for Germany would be lower compared to the USA.

The question of the extent to which Germany as a national economy is affected by transition risks also allows conclusions to be drawn about the threat to German government bonds. The lower emission intensity of the GDP is a first indicator of lower risks for German government bonds. As mentioned above, a final analysis of the effects of transition risks on the German economy – and through tax revenues on the solvency of the German state – would only be possible through an in-depth analysis of the transition capability of German companies and the German economy.

4.2.2.4 Excursus: Effects of transition risk of other countries on Germany

Germany has the largest export surplus in the EU (eurostat 2015). According to the Statistisches Bundesamt (2015), just under a quarter of all jobs, therefore, depend on exports. Figure 15 shows that Germany is predominantly dependent on European countries, which tend to have lower transitional risks than other world regions (see analysis of the emission intensity of the GDP in Chapter 4.1.6.3).

Figure 15: Importance of different world regions for the German trade



Source: Statistisches Bundesamt (2015)

Given the high level of interconnectedness of Germany's trade, climate policy regulations in other countries can have an influence. In addition to international trade, the increasingly interconnected global production chains are another important aspect. At all production levels, a sharp increase in cross-border flows has been recorded in recent years (Statistisches Bundesamt, 2015). The associated transition risks are difficult to capture as they are very sector- and company-specific. A study is therefore not possible in this report.

4.2.3 Overall view of the German financial market

A simple quantitative extrapolation of the emission intensity from the analysis of the equity funds to the entire financial market is problematic because it does not include important asset classes, in particular, loans and government bonds.

Loans include both different financial instruments (mortgages, covered bonds, and book credits) as well as various debtors (companies, private households, and governments). A major portion of the balance sheet total of banks consists of book credits (Deutsche Bundesbank 2016b). Loans also play an important role in primary insurance companies, including pension funds: loans to banks and covered bonds combined account for more than 30% of investments (GDV 2016a).

Both asset classes are accompanied by challenges on assessing their transition risks, such as data availability[64].

Because of these methodological challenges and insufficient data, the extrapolation for the overall financial market is based on assumptions about the total exposure of the German and global economy to transition risks.

It is assumed that the financial market follows the economic development, which implies that the sector distribution of financial market investments is identical to the sector distribution of the GDP. For domestic investment, the maximum impact of transition risks on the German GDP in 2015 is therefore used as an approximation to transition risks with 1.5 to 4.7% (mean value of 3.1%). The figure is based on German emissions for the year 2015 according to UBA (2016a) multiplied by the external costs of EUR 48-144 (mean value of EUR 97) per tCO_2 (interpolated from the values for 2010 and 2030 according to UBA 2012b) divided by the German GDP (Statistisches Bundesam2016a), inflation-adjusted for the year 2010 (World Bank 2016c). Given the same CO_2 prices, the global GDP decline is in a similar range (1.7-5.1% of the GDP in 2014) for data on emissions by PBL (2015), for GDP according to the World Bank (World Bank 2016b) and exchange rates by Oanda (2016).

If domestic and foreign investments were affected by losses of 1.5% to 4.7%, this would correspond to losses of EUR 262-655 billion.[65] Compared to the historical volatility of the financial market and taking into account the low probability of these losses occurring in one day, this alone is very likely to pose only a minor risk to financial market stability.

The analysis results are also subject to a number of limitations: It is difficult to assess the probability of the occurrence of the transition risks and how suddenly such a shock might occur, since this depends, i.a., on the probability and predictability of regulation in Germany and other countries. Furthermore, the calculation does not take into account any adaption measures. The above figures thus represent the rough estimate of an extreme scenario. Moreover, the sample of the German equity fund market does not allow for an individual assessment of concentration risks and the resulting impact chains.

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[64] Other methodological questions are how to assign emissions to an investor in government bonds: Should a country's emissions footprint be used based on consumption or production data, or should only the emission intensity of government revenues be considered? And is the allocation to investors according to emissions per unit of GDP or unit of debt? Together with the Global Footprint Network, South Pole Group is working on methods for meaningful calculations for the emission footprint of government bonds (Global Footprint Network 2015).

[65] Based on a total volume of the financial market of 13.1 trillion EUR (Deutsche Bundesbank 2015a).

4.3 Impact on financial market stability

So far there have been very few studies that cover the materiality of risks related to climate change and financial market stability. According to the classification of risks set out in Chapter 2, primary, secondary, and tertiary effects can be distinguished. The materiality of the risks is therefore also to be assessed on the basis of these three categories, based on the previously analysed sample and the available literature.

4.3.1.1 Primary and secondary effects

Primary effects (e.g. higher energy costs for financial market actors) do not seem to have a dangerous impact on financial market stability (see, for example, Caldecott 2014a, 2014b)

Secondary effects refer to the impacts of climate change risks on the portfolios of investors. In this study, it was shown that, depending on the scenario, investments in the oil, gas, and coal industries could lose substantially in value. According to this study, the entire German financial market could suffer a loss of EUR 262 to 655 billion at the maximum, (about 2-5% of the financial market), wherein tertiary effects are considered since interbank loans are included in the entire German financial market. If the losses in value were to be reflected only in the form of secondary effects on the equity market (about 2-5% loss in value), the stability of the financial market would hardly be threatened, since historically there have been higher single-day losses without subsequent financial crises. According to the model of the "Financial Risk Meter" of the Humboldt-University in Berlin, corresponding losses in the value of the Dow Jones Industrial Index at the end of 2014 would have resulted in significantly higher risks to the financial market, but the Financial Risk Meter would still have indicated a lower risk assessment than for the entire first half of 2016[66].

Another perspective is added by a study by Weyzig et al. (2015) calculates that there is a substantial exposure to fossil fuels in the portfolios of European financial institutions through equities, bonds, and loans. According to the estimates of Weyzig et al., the investments in oil and gas and coal-mining companies are between EUR 460 to 480 billion for the surveyed European banks, between EUR 300 to 400 billion for insurance companies, and 260 to 330 billion EUR for pension funds. A devaluation of these approximately EUR 0.9-1.2 trillion of investments could be problematic. By way of comparison, the US subprime loans, which triggered the financial crisis in 2007, had a roughly comparable dimension (Clerc 2016).

A very concrete case study of such devaluation of equity values was considered by means of the modelling of the price development of five large oil companies in the case of different oil price scenarios. It can be assumed that the modelling would have resulted in similar results for a large number of the remaining oil companies in the sample. An example showing similar dynamics in the past is the US coal industry. Due to the emergence of cheap shale gasses and both stricter and additional regulations of the Environmental Protection Agency, at least 26 coal companies filed for bankruptcy between 2010 and 2013 (Carbon Tracker Initiative 2015).[67] There has, however, not been a negative impact on the financial market stability.

So far, there are only two studies dealing with the question of how such losses in value resulting from interventions affect diversified portfolios. These are the studies "Unhedgeable Risk – How Climate Change Sentiment Impacts Investment" (University of Cambridge Institute for Sustainability Leadership (CISL 2015)) and "Investing in a Time of Climate Change" (Mercer,

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[66] Email-Information from Lining Yu, Humboldt-University, Berlin, School of Business and Economics, Ladislaus of Bortkiewicz Chair of Statistics, July 14, 2016

[67] It is not clear how much impact the drop in demand and the increasing competitive pressure had on this.

2015), both using physical and transition risks to create stress testing scenarios, which they apply to typical portfolios of investors.

Both studies cite that yield reductions can be mitigated by adjustments to the investment allocation along the dimensions of sector, geography, and asset class. While Mercer does not quantify these effects, CISL (2015) suggests that up to 50% of the losses can be prevented. At the same time, this means that a substantial proportion of the risk could only be reduced by system-wide actions. In both analyses, it is difficult to quantify the extent to which potential future developments are discounted.

4.3.1.2 Tertiary effects

Tertiary effects refer to the impact of risks between financial market actors. As the risks can be transferred across different channels between actors, it is difficult to make a comprehensive assessment of the tertiary effects. However, a first indication of the importance of this perspective can be found in the discussion of the financial interconnectedness among actors: In the middle of 2015, for example, German banks held mutual claims of EUR 1.8 trillion, which corresponds to almost 14% of the total financial market (Deutsche Bundesbank 2015a).

The analysis of interdependence in the economy and the transfer of this approach to the financial market have only been developed in recent years and are gaining increasing attention (Härdle, 2015). An example of negative feedback is an affected banking sector, which can subsequently support macroeconomic growth, but only to a limited extent. This, in turn, restricts the ability of the state to reform the banking system. These feedback effects were seen as major sources of risks for the Eurozone in 2011 and 2012 by the European Central Bank.

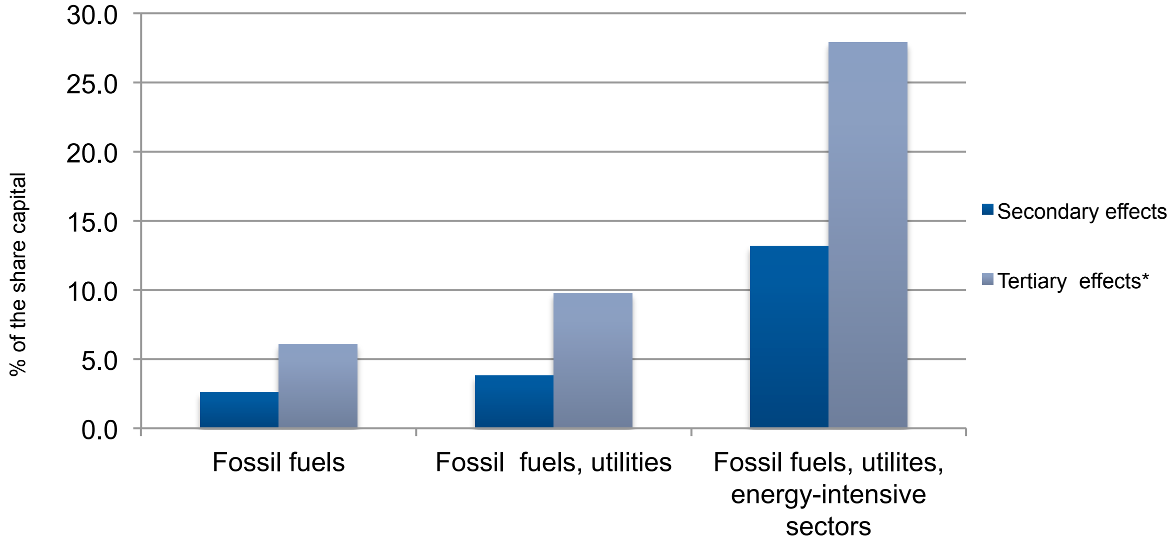
A study published in February 2016 examines the effect of a complete devaluation of companies in climate-sensitive sectors on the equity investments of the 50 largest market-listed EU banks (Battiston et al., 2016). This includes fossil fuels, utilities, and energy-intensive companies, such as aluminium, steel, and cement production.[68].

An overview of the effects according to Battiston et al. (2016) can be found in Figure 16. The secondary effects show the portfolio losses of the direct investments of banks, the tertiary effects the losses through equity investments in banks affected by secondary effects. Although the assumed shock scenario can be regarded as unlikely, the significance of the tertiary effects is still evident: they exceed the secondary effects by a factor of two to three.

In the detailed analysis by Battiston et al. (2016), two German banks are also mentioned among the 20 potentially most affected institutions. Deutsche Bank is mainly affected by secondary effects. In case of Commerzbank, losses are primarily or exclusively due to tertiary effects.

[68] For the exact classification of this group of companies, the study has used the list of sectors „deemed to be exposed to a significant risk of carbon leakage for the period 2015 to 2019“ compiled by the European Commission (2014)

Figure 16: Effect of a 100% depreciation of the equity investments of the fifty largest listed banks in the EU in companies in climate-sensitive sectors in percent of the share capital of the banks (*the values are subject to an uncertainty margin of +/- 0.1-0.45%)



Source: South Pole Group based on Battiston et al. (2016)

In addition to direct equity investments, there are numerous other relevant potential analyses. For example, an analysis of the possible impact of climate change on interbank loans (Battiston et al., 2016) and the interconnectedness of banks and central banks and their dynamic changes (Betz, 2014).

The precise modelling of the tertiary effects remains a challenge. It is, however, clear that an assessment of the systemic financial market risk due to transition risks must necessarily take them into account. Otherwise, not only the extent of the risk could be significantly underestimated, but also its impact on the stability of the financial market, such as the ability of banks to lend.

4.4 Conclusions

Primary effects are only marginally relevant because of the own low emissions of financial market actors; transitional risks have a primary impact on the financial market through the investment of German financial market actors in affected companies (secondary effects). With CO_2 price scenarios or assumptions about the general depreciation of investments in certain industries, methods are available for the assessment of the possible magnitude of transition risks.

If, for example, the equity funds examined within the scope of this study were to bear their financed emissions in the oil and gas, utilities, commodities and industrial sector, this could result in costs of up to EUR 4 billion, an equivalent of 4.5% of the investments in those sectors and 1.2% of the total investment. Equity funds represent, of course, only a fraction of the financial market. Assuming that based on a high interdependence of the financial market with the general economic development, the economic cost of climate change of about 2-5% of the GDP (scale for both Germany and globally) is largely applicable to the German financial market, this would correspond to losses of EUR 262 to 655 billion.

An assessment of the probability of the occurrence of the transition risks and how suddenly such a shock might occur is difficult to make. This depends, among other things, on the probability and predictability of regulations in Germany and other countries. The above figures thus represent an extreme scenario.

Transitional risks of a maximum of 2-5% of the financial market value are very likely to present a low risk to financial market stability considering historical volatility and the low probability of a single-day transitional shock of this magnitude. However, the secondary effects analysed can lead to problematic effects depending on the structural characteristics of the financial system, such as its interdependence and overall stability.

5 Pricing climate risks

5.1 Introduction

This chapter analyses which sectors, assets, and asset maturities are mostly affected by climate change, how climate risks can be integrated into and priced in traditional and modern investment evaluation procedures (Chapter 5.2), to which degree those risks are already factored in today, and to what extent specific securitisation can help to outsource disaster risks.

5.2 Affected sectors, assets and maturities

5.2.1 Sectors

Transition risks

If only the German greenhouse gas emissions are considered,, especially the energy (utilities), industry (primarily steel, cement), transport, and construction sectors are affected by climate risks. Through the transport sector, the automotive sector is also affected. However, not only the German emissions are important for the entire German financial market. Although the same sectors are affected, globally the energy industry and building sector are less important than in Germany, while the land use sector and other emissions from energy supply (especially methane emissions from the extraction and transportation of fossil fuels) contribute more emissions, see Chapter 4.

Broken down to individual companies that are based in Germany, we see a very similar sectoral picture (see Figure 17): three energy companies (RWE, E.ON, and ENBW) account for 38% of the emissions of the 250 largest producers with German headquarters in 2014, while the four largest industrial companies (Heidelberg, Thyssen, Linde, and BASF) accounted for 24% of the emissions. The building and transport sector is not among the largest producers, since the emissions are mostly decentralised[69]. The emissions of the 250 largest producers in Germany amounted to 580 million tCO_2e in 2014, which was about 60% of the emissions of Germany in the same year (UBA 2016b).

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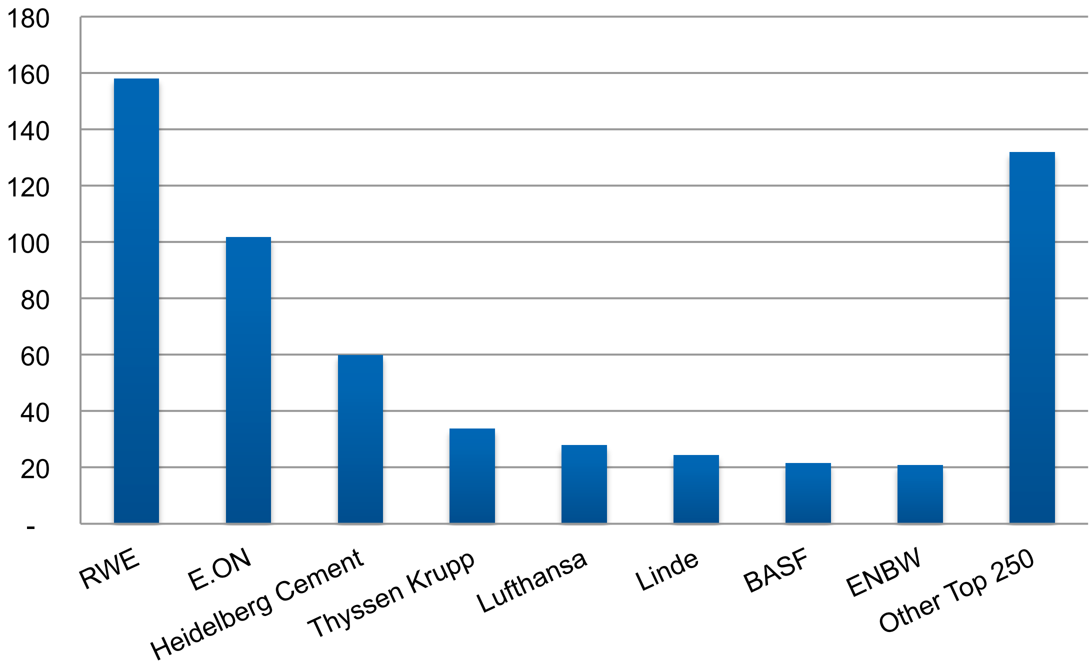
[69] Even though Lufthansa is among the eight largest CO_2 producers in the transport sector, most of the Lufthansa emissions are not represented in the German CO_2 statistics in Figure 17 as no emissions from international air traffic are recorded.

Figure 17: Largest German CO_2-producers 2014 (in millions of tons CO_2e)



Source: South Pole Group, based on South Pole Group database (CDP and company reports)

Physical risks

Factoring in of physical risks is globally necessary, especially in the following sectors, that are most affected by climate change according to the IPCC (Arent et al., 2014): energy, water, transport, tourism, agriculture, infrastructure, and healthcare[70]. As already explained in Chapter 3, in the financial sector, the insurance sub-wsector is directly affected by increased claims resulting from weather-related damage and variability. The remaining financial sector is hardly exposed directly, but rather indirectly through secondary effects (investments in affected sectors) to the physical risks.

In Germany, basically the same sectors are affected by climate change as worldwide, albeit to varying degrees. Therefore, the German financial market is indirectly affected by climate change, both through international as well as national investments in the energy, water, transport, tourism, agriculture, infrastructure and healthcare sector.

Maximum relevance for the financial market

Transitional risks and the associated liability risks are of greater importance for the German financial market (approximately 2-5% of the asset value are potentially at risk even in the short term, if investments are affected along the German or global GDP) than the physical risks (approximately 0.1-0.6% are at risk long-term, for investments along the German GDP, and up to 3% for investments along the global GDP and moderate global warming of 2-3° Celsius). See Table 6. Therefore the factoring in of transition risks, in particular in those sectors in Germany with high GHG emissions (primarily energy sector and industry), seems to be of paramount importance. In the case of 6 energy and heavy industry companies in the DAX, when factored in

[70] In the healthcare sector, there will be higher costs and an increasing demand for services resulting from climate change.

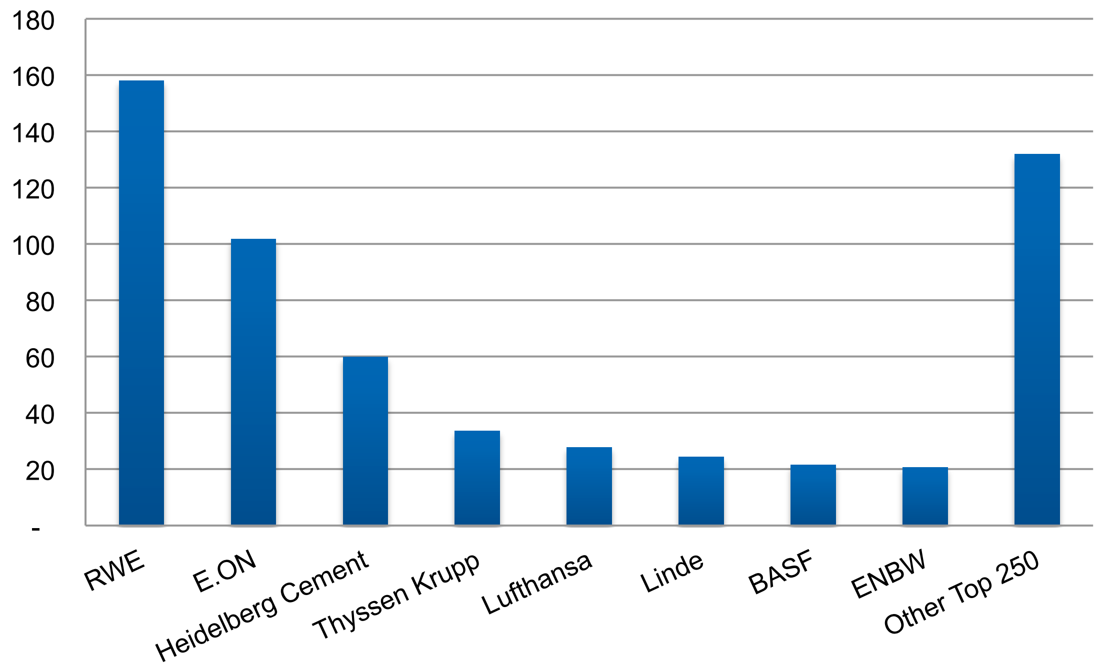
completely, the social costs of carbon would exceed 10% of the total earnings according to UBA (2012b)[71]. In general, the spread of the effects of a given CO_2 price on companies is large.

The exposure of RWE and E.ON to climate change costs is also high on an international level. According to Bassen et al. (2016), the CO_2 costs for RWE and E.ON would be more than 100% of their profit, if not only today's CO_2 prices, but the full social costs of 80 EUR/tCO_2e according to UBA (2012) incur. This applies even if the suppliers could pass on 50% of these CO_2 costs to their customers.

The focus on German companies disregards the fact that German financial market actors are making a significant part of their investments (approximately 40% of all loans) internationally Deutsche Bundesbank 2016b). The literature on the economic costs of global climate change (Dietz, Bowen, and Dixon 2016, Arent et al., 2014) suggests that, even in the case of international investment, the transition risks do not deviate significantly from 2-5% of the vulnerable investment value.

However, Battiston et al (2016) infer a significantly higher vulnerability when secondary effects through investments between banks and banks' effective equity capital are taken into account. See discussion in Chapter 4.

Figure 18: Largest German CO_2-producers 2014 (in millions of tons CO_2e)



Source: South Pole, based on South Pole Group database (CDP and company reports)

[71] Own calculation based on the South Pole Group data base (CO_2 emissions Scope 1 & 2 and revenue by company in 2014) and UBA (2012b) for CO_2 costs (interpolation for 2014 based on values for 2010 and 2030)

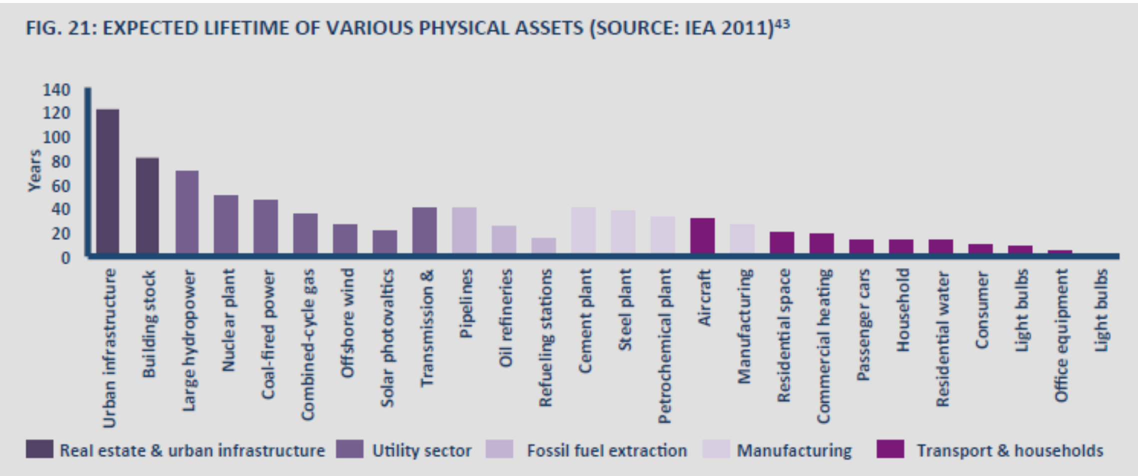
5.2.2 Maturities and lifetime

The extent to which different maturities of assets are affected in the context of climate change depend largely on two factors: firstly, the period in which the (increased) occurrence of the various climate risks can be expected and secondly, the different lifetime (maturities) of the various technologies and investments.

The maturities of climate risks are different for physical risks, which occur mainly in the medium and longer term, and transition risks that already occur today, but increase in the longer term according to expert interviews (see Table 6).

The lifetime of different physical investments for selected sectors are shown in Figure 18. Lifetime is relevant under two aspects. First, at the time of the construction of a plant, it allows clarification regarding the time horizon for which future climate risks have to be assessed. When building a coal-fired power station with a service life between 40 and 60 years today, it must be taken into account that climate risks that materialise during this period could lead to a loss of value of the plant. Secondly, this information is necessary to calculate the loss of value resulting from the occurrence of a climate risks at any given moment in time (X). To stick with the example of the coal-fired power plant: if, e.g. a CO_2 tax makes the operation of the power plant unprofitable and it has to be taken off the grid, the lost profits are calculated from the theoretically remaining service life at time X. Figure 18 shows, inter alia, that urban infrastructure (e.g. roads and underground rail network), buildings, and most power plants have a long lifetime. As these investments are within the sectors affected by climate risks, it is advisable to already factor in climate change in these sectors, especially in the case of longer-term investments.

Figure 19: Expected lifetime of different physical assets



Source: IEA (2011)

5.2.3 Asset classes

When it comes to physical risks that occur in the form of long-term changes (for example the increase in water temperature and changes in water availability), especially longer-term physical assets (agriculture, forestry, real estate, and infrastructure) are affected. In case of financial assets, such as equities and bonds, investors can usually divest financial assets much faster than in case of tangible assets (with the exception of loans with very long maturities).

In the case of physical risks occurring in the form of extreme events, all types of assets are affected, i.e. also market-listed equities and tradable bonds, which can be sold quickly but whose value can also change immediately upon the occurrence of an extreme event. The longer-term investments (property, plant and equipment, and financial assets with longer maturities) are again more affected as investors cannot divest these assets as quickly, and are therefore directly exposed to the risks.

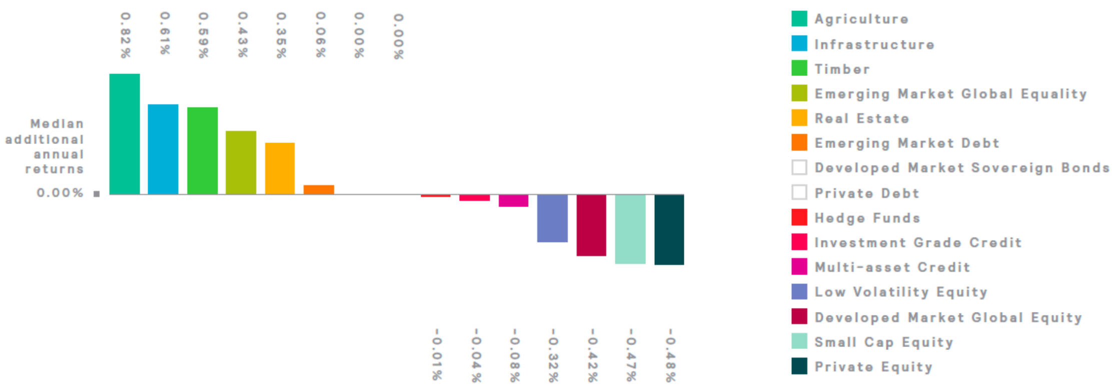
In a 4°-scenario, in which physical risks occur, Mercer has assumed lower returns in the next 35 years especially for the following asset classes: agriculture, forestry (timber), real estate as well as global equity markets. In all other asset classes, the effects are either positive (in the sub-scenario with only little damage, see Figure 19) or only slightly negative (in the sub-scenario with high damage, not shown).

Figure 20: Impact of climate change on the average annual yield of different asset classes over the next 35 years; 4°-scenario "Fragmentation (little damage)"

Source: Mercer (2015)

In the case of transition risks, as discussed in Chapter 4, equity and, in part, debt assets are affected. Mercer (2015) predicts a drop in asset value over the next 35 years for a variety of types of equity investments (except in emerging markets) and to a lesser extent for loans (except in emerging markets), see Figure 20.

Figure 21: Impact of climate change on the average annual yield of different asset classes over the next 35 years; 2°-scenario "transformation"



Source: Mercer (2015)

5.3 Factoring into investment evaluation

Climate risks can be factored in by integrating them into different existing models for investment evaluations.

5.3.1 Different methods for factoring in

The most common method for investment evaluations is the **discounted cashflow method,**in which the Net Present Value (NPV) of a project is calculated, which is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyse the profitability of a projected investment or project.

$$NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

N – is the total number of periods

t – the time of the cash flow

i – the discount rate, i.e. the return that could be earned per unit of time on an investment with similar risk

R_t – the net cash flow i.e. cash inflow – cash outflow, at time t

As long as the net present value is greater than zero (or the best alternative), it is worth investing.

In the net present value method, there are different ways of factoring in climate risks. Initially, expected changes can be factored into cash flows, in the earnings (e.g. lower electricity sales due to climate-induced lower availability of water), the operational costs (e.g. CO_2-levies, costly maintenance), or the investment costs (e.g. higher dams due to higher floods). Secondly, climate risks can be factored in by increasing the **discount rate**. Both physical risks (e.g. volatility of water availability), as well as transitional risks (e.g. regulatory interventions to contain CO_2 emissions), can lead to an increase in the discount rate.

One common way to estimate the discount rate is to use the c*apital asset pricing model*:

$$Expected\ return = Risk\ free\ rate + \beta\ (expected\ market\ return - risk\ free\ rate)$$

In this model, β (beta) is a measure for the risk of an investment. Therefore, by modifying beta, climate risks can be taken into account. The adjustment of beta, and thus the expected return, can be applied not only to individual projects but also to entire companies and countries. That way, climate risk can be factored into the assessment of the expected return on investment and the creditworthiness of companies (Germanwatch et al., 2009).

In addition to the commonly used NPV method, there are other methods used in the market. A simple measure is the **payback period**, in which the number of years is calculated, that is necessary to repay the initial investment. In this case, climate risks can only be considered in the cash flows, but not in the discount rates.

A more complex consideration of investments is the **real options valuation (ROV)**. For the ROV, it is assumed that investors have the option to invest but can also defer this option up to a certain time *t* (expiration time). This option for a certain period has a financial value, both due to the current investment value of the non-invested capital, as well as the reduction of uncertainty.

The longer an investment can be deferred, the lower the uncertainty of the investment in this period. This reduced uncertainty is especially financially attractice when an investment is risky, i.e. the variance of the return of the respective investment is very high (Luehrman 1998). For ROVs, investors can factor in climate risks by taking into account the increased variance in the returns of affected investments (such as investments in fossil fuels or transport infrastructure).

As a result, real options become more valuable, and investors would tend to postpone investments in order to reduce uncertainty (with regard to climate change and climate policy).

In addition to factoring climate risks into individual investments, investors can factor them into their portfolios as well, i.e. by **diversifying** their investments differently than usual. Diversification is a general strategy to reduce portfolio risks, e.g. by investing in as diverse sectors as possible or by following certain indices (e.g. DAX) in order to avoid excessive exposure to the risks of individual sectors. In the case of climate risks, a sectoral diversification according to general economic criteria allows only a limited reduced risk since almost all economic sectors are affected by climate change. It is, therefore, appropriate to rather actively manage the climate risk (Germanwatch, et al., 2009), e.g. by ensuring that investments in fossil fuels are rather underweighted compared to the general equity market. This may even lead to the exclusion of certain technologies, e.g. coal power, if these lead to a risk measure beta which is too high for certain for certain investors.,

5.3.2 Practical challenges

While it is theoretically possible to factor in all different type of climate risks into existing investment valuation methods, in practice, there are several hurdles, e.g. the uncertainty about the occurrence of physical risks and the assumptions for the CO_2 price: should current CO_2 prices (approximately EUR 5-10 per tCO_2e in EU emissions trading), future expected CO_2 prices, or even the external costs (EUR 40-120 per tCO_2e in 2010 according to UBA (2012b)) be assumed? How much of an impact are the effects of climate change going to have on the water cycle in the next 50 years?

The complexity of factoring in climate risks is now show with a case study (hydropower).

5.3.3 Case study: Factoring in of climate risks in the case of a hydroelectric power plant

A 20 MW hydroelectric power plant in the EU is used as a fictitious case for factoring in climate change risks. Based on IEA (2010) and IRENA (2012) the following assumptions are made: investment costs of EUR 2,000 per kW, operational costs of EUR 15 per MWh, a capacity factor of 55%, an expected return of 6.6% and a feed-in tariff of EUR-cents 5 per kWh. On the basis of a simplified NPV-model, in the scenario without climate risks, an NPV of more than EUR 2 million is calculated for the power plant, which would make the investment worthwhile for investors (see Figure 21).

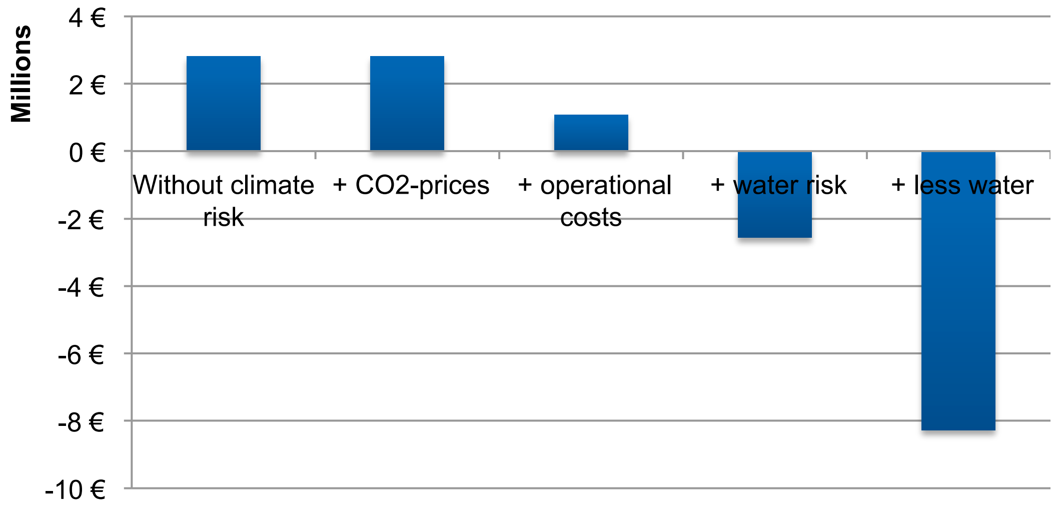
If the investor now factors in the transition risks, they can expect a similar profitability: the power plant causes almost no CO_2 and is not subject to emission trading as renewable energy facility. In many countries, power plant operators benefit from the use of hydropower as a renewable form of energy. We do not assume a net effect of any transition risks, which means that even after factoring in the transition risks the NPV remains at at EUR 2 million (see Figure 24).

If the investors now also factor in the physical climate risks, they have to consider several factors. First, the operational costs could increase, e.g. due to increased weather damage or silting up of reservoirs. If based on historical data trends or future expectations, we now assume operational costs that are 10% higher due to climate change, the NPV would decrease to approximately EUR 1 million. Next, due to climate change, the variability and thus the uncertainty of water availability can increase. The investor can factor in this risk by increasing the expected return (either through a higher equity ratio or by adjusting the beta in the capital pricing model). If the expected return is increased by 1.2%, the NPV of the investment is negative (minus EUR 1 million), and the investment is no longer worthwhile. Last, the average expected water availability can also change. If the water availability decreases by 10%, the NPV becomes even more negative (see Figure 24).

If the investor is able to defer the investment by five years, according to real option valuation, the value of this option should be increased due to climate change, as the investor is not affected by increased variability in returns due to climate change during the five-year deferral.

The fictional example shows that climate risks can theoretically be factored in, but that certain data (in this case CO_2 prices, forecasts on water availability and their variability, and increased weather damage) is required, which is not available in practice or can only be estimated using prognostic models.

Figure 22: Factoring in of climate risks into the NPV of a fictitious hydropower plant



Source: South Pole Group

5.3.4 Overview for potential factoring in (focus an method)

Table 6 provides an overview of climate risks, maximum amount of factoring in, the sectors concerned, assets, maturities, and the possibilities of factoring into existing investment valuation methods.

Table 6: Climate risks by maturity and sectors

Climate risks	Maximum value of the factoring in (loss of value on the financial market)	Maturity / lifetime of effects	Affected sectors (primary effects)	Affected assets	Factoring in
Physical risks (long-term effects and extreme events))	0.1-0.6% for investments along the German GDP; 0-3% at 2-3° C (much more with stronger warming) and assuming full international interdependence, see chapter 3.	Rather long-term (from 2030)	Insurance, agriculture, health sector, tourism, energy sector, water sector, infrastructure	Chronic changes: mainly fixed assets (infrastructure and buildings) with maturities> 10-15 years; extreme events: all assets	Adjustment of the present value (mainly negative due to chronic damage /insurance) as well as the yields/betas (extreme events)
Transition risks (regulatory, technological and sales market risks)	Maximum 2-5% for investments along German or global GDP; 4% in the case of German equity funds, see Chapter 4	Partly in the short term, increased in the medium and long term	Emission-intense industries (energy, cement, steel, automobile industry), buildings	All assets, including financial investments (esp. listed shares, bonds)	Adjustment of the present values (for example CO_2 price) as well as of the yields/ betas (esp. energy sector)
Liability risks/ reputative risks	Maximum 2-5% for investments along the German GDP for emissions in 2015; 28-81% for historical emissions 1990-2015.	Rather in the medium and long term (from 2020/2030)	Emission-intense industries, potentially financial institutions	All assets, incl. listed shares, bonds, loans	Adjustment of the yields/ betas (esp. energy sector)

Source: Chapters 3 and 4 for the economic relevance of physical and transition risks; own calculation for liability risks, interviews and Germanwatch et al. (2009) for maturities; Arent et al. (2014) as well as interviews for affected sectors. The liability risks were calculated as follows: historical and projected emissions according to UBA (2016a) multiplied by the social costs per ton of CO_2 (UBA 2012b) divided by the German GDP (Statistisches Bundesamt 2016b), inflation-adjusted for the year 2010 (World Bank 2016c)

5.4 Existing pricing of climate risks

This chapter examines whether there may already be a “reasonable pricing” of climate risks in certain sectors, assets, and maturities that corresponds to the effective costs and risks.

We distinguish between a rather generic approach to climate change, as used by most financial market actors according to expert interviews, and the pricing with concrete figures, as only a minority of actors does[72]. Examples of concrete pricing exist in the insurance industry, which continually incorporates adjusted weather damage into the insurance models, and in the energy industry, which is already extensively dealing with today’s and future CO_2 prices, especially in case of longer-term investments.

[72] The findings of the expert interviews are broadly consistent with the results of an earlier study (Germanwatch et al., 2009), according to which two-thirds of German investors are looking at climate risks, but in most cases are not taking concrete figures or non-formalized methods for sales/profits into account.

In addition to pricing of own operational activities, companies can also send out signals that facilitate the factoring in of climate risks for investors. These signals include i.a. reporting on climate strategy, risk exposure (CO_2 emissions) and measures. Several hundred companies report to CDP every year, and other companies provide annual- and/or sustainability reports.

5.4.1 Pricing transition risks

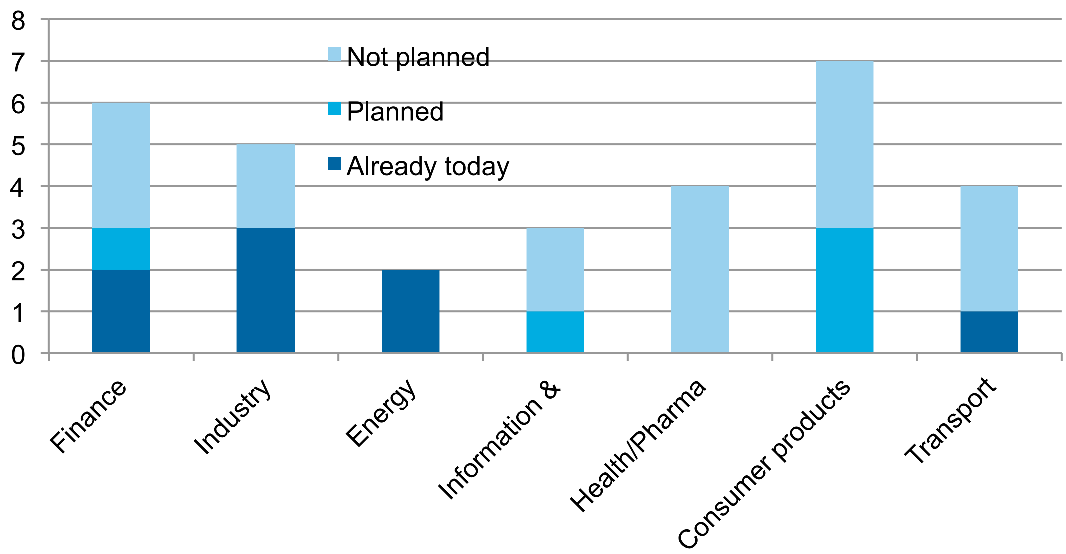
Today, transition risks are factored in by means of CO_2 prices, the exclusion of certain companies according to an analysis of climate risks, or the disinvestment of fossil energies.

5.4.1.1 CO_2 prices

CO_2 prices are certainly the most common means of factoring in climate risks, as the risks of the introduction and the tightening of various regulatory instruments in climate policy (taxes, emissions trading, and technology standards) can be captured well inexpected CO_2 prices.

More and more companies use internal CO_2 prices in their reporting. While only 150 companies reported such internal CO_2 prices in 2014, in 2015, the number had already grown to 437, with another 538 companies planning to introduce an internal CO_2 price in the future (CDP 2015c). Thirteen German companies, including eight DAX companies, and two commercial banks, have reported that they are using an internal CO_2 price, while another eight German companies (5 of them DAX companies) have announced the introduction of such an internal CO_2 price (see Figure 22). With regard to **sectors**, especially companies in the emission-intensive energy supply and industrial sector as well as the financial industry factor in CO_2 prices. Surprisingly, only a few companies in the transport sector report internal CO_2 prices. Within the financial sector, according to expert interviews, CO_2 emissions are primarily factored in for utilities and multinational oil companies.

Figure 23: DAX companies using internal CO_2 prices (by sector)



Source: South Pole, based on CDP (2015c)

Only two German companies have published the internal carbon price to the CDP (USD 7 and 22 to 45 per tCO_2e). Our expert interviews suggest that most financial institutions (especially the asset management departments), if they even assume carbon prices at all, are more oriented towards current market prices in the emissions trading system of about 5 to 9 EUR/tCO_2e (2015/2016).

Thus, the internal CO_2 prices used by a minority of Germany companies and financial market actors are in the lower range of the globally reported CO_2 prices of 1 to 357 USD/tCO_2e (CDP 2015c) and significantly below the effective social costs of EUR 40 to 120 per tCO_2e in 2010 and at EUR 70 to 215 tCO_2e in 2030, as estimated by the UBA (2012b). It should be noted that the low CO_2 prices could also reflect the fact that the companies assume that the majority of CO_2 costs are not borne by them as direct producers, but by the consumers of the produced goods.

The approach of CO_2 pricing also has certain limitations. Important elements for the comprehensive assessment of transition risks are disregarded, e.g. the climate strategy of a company, cost-effective mitigation potential, price elasticity of product demand, and the development of new technologies and other measures to reduce the exposure to CO_2 emissions in the long term.

5.4.1.2 Exclusion, disinvestment, and hedging

According to interviews, investors not only factor in transitions risks through CO_2 prices, but also look at **the general exposure to climate policy** (e.g. investments in fossil energies, development of alternative technologies). To some extent, companies that are still investing in coal-fired power plants or whose revenues are substantially dependent on them are excluded from certain portfolios. The approach of the **exclusion** has the limitation that transition risks are not factored into non-excluded companies.

Another way of factoring in is the **full or partial divestment in fossil fuels**, especially in case of divestment from mineral oil corporations and coal-producing industries. This decision can be made based on a number of reasons: ethical considerations, the assumption of a specific CO_2 price, or the risk that investment in fossil energies could be a complete loss due to climate policy measures. In Germany, seven financial institutions and organizations have a divestment strategy, including Allianz and the Deutsche Presseversorgungswerk (partial disinvestment), the Steyler Ethikbank (disinvestment of coal), and several non-profit organizations (Go Fossil Free 2016)

According to a quantitative study, dinvestment strategies have already led to lower market values of coal-producing companies (Byrd and Cooperman 2015). Divestment strategies cannot fully factor in transition risks, as they are focused only on a few companies that mine fossil fuel and not on all companies that produce greenhouse gases (Covington and Thamotheram 2014). The approach of divestment has, therefore, the limitation that transition risks are not factored into all those companies that are not affected by disinvestments

Another possible way of factoring in is **hedging** against climate risks, for example, in the form of options or futures. While hedging is possible for individual investors (Andersson et al., 2016), this strategy will not work for the financial sector as a whole, as climate change means losses for most sectors and, therefore, all actors are hedging in the same direction (CISL 2015).

5.4.1.3 Factoring in by asset class, maturities, and sectors

According to expert interviews, the factoring in of transition risks takes place in all asset classes, but mostly in **longer-term investments** (infrastructure and bonds with longer maturities) and **equities**, and less in **short-term corporate bonds**. The CO_2 emissions for government bonds are scarcely factored in. In term of sectors, the climate risks are factored in particularly when **investing in utilities** and, in some cases, in energy-intensive sectors.

In addition to the expert interviews, international studies also show signs that factoring in is, in fact, taking place.

For ***equities,*** different results can be found in the literature. In some cases, CO_2 risks do not have any effect, and in other cases, they lead to price losses on the equity market. In the EU and the US, the general capital costs of a CO_2-intensive company have increased (Chen and Silva Gao 2012, Koch and Bassen 2013). The situation seems also clear for the announcement or the implementation of emission trading systems: several studies have confirmed losses in value of CO_2-intensive companies for Australia (Chapple, Clarkson and Gold 2013) as well as for the EU (Koch and Bassen 2013). The price losses usually correspond to CO_2 prices within the framework of the politically set prices, e.g. 17 to 26 AUD in the case of Australia (Chapple et al. 2013) and not the effective social costs. According to a study by Bassen et al. (2016), which considered more than 4,000 companies worldwide, companies with a lower CO_2-intenity have a higher price-to-book ratio. According to the authors, the financial markets seem to "increasingly perceive low CO_2 emissions as an indicator of future value creation potential and growth opportunity, and partly factor this in" (Bassen et al., 2016, p. 33)

For **corporate bonds**, Chen and Silva Gao (2012) find higher interest rates in companies with higher CO_2 intensities (while controlling for other factors affecting interest rates). However, this result would have to be confirmed by other studies before we can speak of a robust link between interest rates on bonds and CO_2 intensity.

5.4.1.4 Summary

In summary, it can be concluded that today, transition risks are only factored in by certain sectors and actors in the German financial market, primarily by the particularly exposed sectors (energy, industry) and commercial banks. This alone indicates that the factoring in of the transition risks is incomplete. Furthermore, the reported internal CO_2 prices are close to the current prices in emissions trading, but far below the real cost costs according to the Federal Agency for the Environment (UBA) and the projected, rising prices in emissions trading. Therefore, it remains unclear whether many companies are prepared for a possible regulatory adjustment of CO_2 prices towards the actual social costs or the expected higher CO_2 prices due to the annual reduction of the number of certificates in the EU emissions trading system.

The collection of information (e.g. on environmental regulations and CO_2 prices) always causes costs, so it is virtually impossible for companies to be fully informed and the market to be efficient (Grossman and Stiglitz 1980). Especially in the case of climate risks, information deficits are large due to the multiple uncertainties (like climate change and climate policy), and therefore a non-efficient pricing is likely (Hjort 2016).

While it is clear from today's (low or non-existant) CO_2 pricing that climate risk management is not economically efficient from a macroeconomic point of view, it is not possible to conclusively determine whether, from a financial stability point of view, investors are "properly" factoring in the transition risks, since this should be based on realistic expectations regarding future and regulatorily influenced CO_2 prices.

Perhaps investors with low internal CO_2 prices have the "correct" perception that the introduction of high CO_2 prices or other major climate-related regulations is very unlikely due to political resistance. From a short-term investment point of view, sufficient information on environmental regulations is available to investors; for medium to long-term forecasts (beyond 2020), however, considerable uncertainty exist regarding CO_2 prices and compliance with the 1.5-2° limit.

5.4.2 Pricing physical risks

The authors are not aware of any general studies on the pricing of physical risks by German financial market actors. According to expert interviews, physical risks are on the radar of most insurers, but an active management of these risks primarily takes place through reinsurers and major property and casualty insurers: they constantly adjust their insurance models based on the development of weather-related damages. However, this adjustment is purely based on historical data and not specifically on knowledge about future climate change. Changes in weather risks due to climate change are therefore factored in the same way as changing weather risks due to other factors.

Furthermore, major players in the insurance industry (Munich Re and GDV) are also conducting studies on longer-term climate change. The results are, however, not directly incorporated into the insurance models. Changing expectations on weather-related damages are often only includes in own models, while the insurance premiums (which could theoretically be adjusted annually) are not always adjusted since insurances fear to lose clients when they increase premiums in today's low interest rate situation.

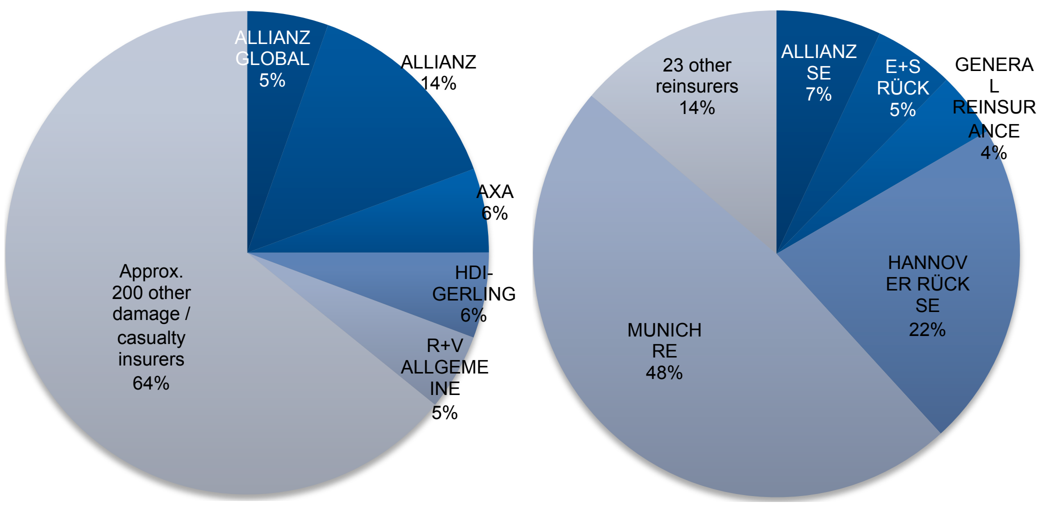
Larger insurance companies also manage physical risks with further measures, including the adjustment of risk capital and diversification of the risks insured. Since the 1990s, insurances and reinsurances have also used so-called **natural catastrophe bonds** (nat cat bonds) to outsource risk (see the case study in Chapter 5.4.3).

Due to pricing based on historical data, insurance companies cannot fully factor in abrupt changes in weather risks that occur within one year. However, the annual premium adjustment permits a relatively short-term adjustment, while climate change-induced changes usually occur over a longer horizon.

The factoring in of physical risks primarily through reinsurers and certain property and casualty insurance companies can be explained, among other things, by the size of the insurers. While reinsurers are relatively large – only five companies share 76% of the EUR 52 billion gross premiums of all German reinsurers (see Figure 23, right), there are over 200 property and casualty insurance companies, of which the largest five share only 36% of the EUR 70 billion in gross premiums (see figure 23, left).

Smaller insurers and companies in other sectors sometimes monitor the physical climate risks; they do, however, not actively factor them in. They also rely on the knowledge of large insurance companies and reinsurances, with the information transferred through premiums, reports an shared data. Banks, asset managers, and pension funds in the financial sector also rely on the knowledge of the insurance industry and therefore consider at most whether companies they are investing in are adequately insured against severe weather damage or whether there are massive physical risks in infrastructure projects on the basis of insurance data. An exception in the financial sector are public sector banks, which are more concerned with adaptation to climate change because of political requirements.

Figure 24: Distribution of gross insurance premiums 2014 from property/casualty insurances (left) and reinsurance (right), which are under federal supervision



Source: South Pole, based on BaFin (2015)

The results are broadly consistent with the results of a study conducted eight years ago (Germanwatch et al., 2009) when the financial sector considered the physical risks of climate change to be of little importance in the short to medium term, as other more important risks were the main focus.

5.5 Case study: catastrophe bonds and climate change

Catastrophe bonds (cat bonds) are special securitizations or securities in which the investor receives an annual coupon for the maturity of the bond,[73] but can lose both this coupon and the invested capital (principal) upon the occurrence of extreme natural catastrophes. For insurers, catastrophe bonds are interesting because they reduce the risks of loss in the event of disasters, as the insurer takes only a part of the risk. For investors, catastrophe bonds are of interest because catastrophe risks are hardly correlated with other financial market risks such as currency risks (Arent et al., 2014).

To what extent can such catastrophe bonds help to price and manage physical climate risks? In order to answer this question, the importance of climate-related events for catastrophe bonds is examined below, and the existing market as well as its ability to expand with regard to investors and competing products is considered.

Natural disasters affected by climate change were contained in 52% to 81% of all outstanding cat bonds at the end of 2015 (see Table 7), in particular hurricanes and other wind events in the USA. Although climate-induced natural catastrophes in Europe (storms) are traded in less than 10% of all catastrophe bonds, the catastrophe bond market is of great importance to the largest German insurers and reinsurers, as they operate globally. Munich Re, for example, has massive provisions for natural catastrophes in the USA (Munich Re 2015) and all outstanding catastrophe bonds from Munich Re include hurricanes or storms in the USA (Munich Re 2016).

Table 7: Climate aspect of various natural disasters in the cat bond market

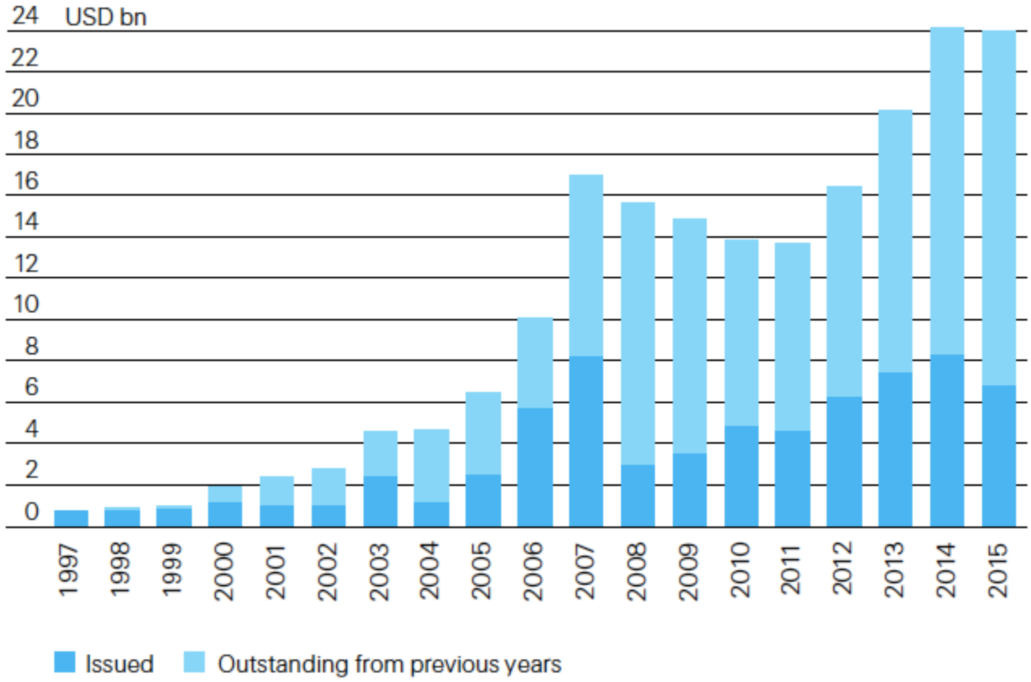
Natural catastrophe	Share of the cat bond market by the end of 2015	Climate relevance
Hurricanes and Other Winds (USA)	52%	Exacerbated by climate change
Earthquake (USA)	47%	No reference
Earthquake (Canada, Japan)	19%	No reference
Storms (USA)	12%	Exacerbated by climate change
Wind storms in Europe	9%	Exacerbated by climate change
Other natural catastrophes Mexico, Australia, Japan	8%	Partially exacerbated by climate change
Total disasters affected by the climate	**52%-81%**	Partially exacerbated by climate change

[73] Normally a reference interest rate (e.g. US government bonds) plus a fixed amount per year.

Source: Swiss Re (2016) for market shares, IPCC (Arent et al 2014) for climate change. Note: Total of the shares in the NatCat Bond market may exceed 100%, as certain catastrophe bonds include several natural catastrophes.

How strongly has the cat bond market developed? Figure 24 shows the rapid historical development of the catastrophe bond market: while before 2000, there was less than USD 1 billion in cat bonds outstanding, it is now USD 24 billion. There was a particularly strong development after the hurricanes in 2004/2005. The market had a sharp slump during the financial crisis in 2008, but recovered quickly, as market participants saw a greater transparency in catastrophe bonds compared to other securitizations such as mortgage bonds (Arent et al. 2014).

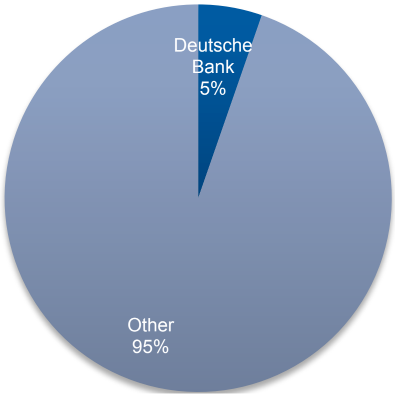
Figure 25: Development of the market for catastrophe bonds

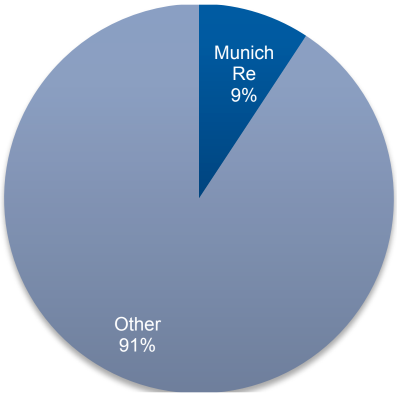


Source: Swiss Re (2016)

German financial market actors have a relevant share in the catastrophe bond market (see Figure 25). With USD 4 billion, Deutsche Bank was the fourth-largest bookrunner in the market between 1997 and 2014 (Swiss Re 2016). At the end of 2015, USD 0.5 billion in own catastrophe bonds from Munich Re and USD 1.7 billion in catastrophe bonds arranged for clients were outstanding. As a result, Munich Re holds a market share of approximately 9%.

Figure 26: Market share of German companies in bookrunning 1997-2014 (left) and outstanding catastrophe bonds, end of 2015 (right)





Source: Swiss Re (2016) for bookrunning, Munich Re (2016a) for outstanding catastrophe bonds at the end of 2015, and Swiss Re (2016) for total market size.

Is the cat bond market viable int the long term and can it contribute to the pricing of climate risks? The historical development shows that the market continues to grow despite a slowdown in 2015 (Swiss Re 2016), and there is still room for further growth, according to interview partners. However, it is very difficult to make market forecasts as the market development depends on various factors (interest rate, demand, know-how, and competing products). Due to the **low level of interest rates,** insurers have excess reinsurance capacity and feel only little pressure to outsource catastrophe risks. In addition to the low interest rate, which reduces the attractiveness of (re-)insurances, investors' **demand for higher risk investments** also plays a role.

Due to the risks involved, catastrophe bonds usually have a credit rating of BB or B, i.e. they belong to the **segment of investments with higher risks and returns**. As a result of regulatory restrictions for investors, this segment will remain relatively small in the future, but catastrophe bonds could increase their market share as disaster risks are only weakly correlated with other risks.

Another factor is the **know-how for issuing catastrophe bonds**. Especially for small insurers, catastrophe bonds are too complex as an instrument, and they rather use reinsurance or require assistance from other companies to issue catastrophe bonds.

Finally, **competitive products** also play a role in catastrophe bonds. The most obvious competitor is reinsurance, which is preferred by many players because of the lower level of complexity, as long as the reinsurers have enough financial capacity, as is the case today. In addition, alternative instruments to mitigate weather risks, such as weather derivatives have been developed (Arent, et al., 2014).

In summary, the development of the catastrophe bond market is not primarily dependent on a change in weather risks due to climate change; general interest rate policy, the associated demand for reinsurance, and the development of competing instruments play a greater role. While cat bonds help the insurance industry manage physical weather risks that are affected by climate change, they only represent one instrument out of a variety of risk management tools. From a financial stability point of view, it is more important to consider whether investors continue to insure themselves against physical risks (and/ or factor them in differently), and whether insurance companies factor weather risks into their insurance products and their risk management. The extent to which cat bonds are used is of secondary importance.

5.6 Conclusions

The pricing of climate risks is particularly important for affected sectors (especially energy and industry regarding transition risks, insurance sector for physical risks), affected assets (mainly fixed assets, but also financial assets), and investments with longer-term maturities. Overall, economically speaking, and because of the shorter duration, the pricing of transition risks (including liability risks) in the German financial market is of greater importance than the pricing of physical risks. However, the two risks become equally important in the long term as the global interdependence of the financial market increases.

At the theoretical level, there are various ways to factor climate risk into existing investment evaluation methods (NPV, ROV), but the implementation is limited due to a lack of data and the uncertainty regarding the physical effects of climate change and the regulatory interventions to maintain the 2° Celsius limit. The physical effects of climate change are very difficult to factor in because they are strongly dependent on very unlikely but exceptionally extreme tail risks, which are extremely difficult to assess (Weitzman 2009).

Today's internal pricing of CO_2 is mainly limited to companies in affected sector (energy and industry) and commercial banks that are heavily invested in fossil fuels, especially with longer maturities and infrastructure investments, equities, and corporate bonds. The carbon pricing (if it is considered at all) is largely oriented toward today's CO_2 market prices, and thus, is significantly lower than the social costs of the CO_2 emissions. From a macroeconomic point of view, this results in incomplete, inefficient pricing of climate change. From the point of view of the individual companies and financial stability, however, today's price could still be efficient if the companies' assumption is correct, that the introduction of high CO_2 prices or other far-reaching climate policy measures is very unlikely due to political resistance. For short-term investments, there is sufficient information on climate policy measures, but there are considerable uncertainties for investments with a horizon beyond 2020-2030.

Factoring in of physical risks hardly takes place outside the insurance industry due to the complexity and the not yet massive damages. The real economy relies heavily on the knowledge of the insurance industry, and the financial sector mainly examines whether firms in which they invest are adequately prepared for severe weather damage through insurance coverage. The insurance industry factors in changes in physical weather risks primarily by improving their models, diversifying risks, and adjusting premiums and technical reserves. The adaptation of the models, premiums and technical reserves in the case of the climate change works the same as in the case of other reasons for changed weather-related lossee: Insurances factor weather risks in based on historical-statistical data and not based on expectations (regarding climate change and other factors). Since the pricing is based on historical data, insurances cannot fully factor in abrupt changes of weather risks. However, the annual premium adjustment allows for a relatively short-term adjustment, and climate change-induced changes usually occur over a longer horizon. Catastrophe bonds help the insurance industry to outsource physical risks, but they are only one instrument out of a variety of risk management tools, and also an instrument that is heavily dependent on larger developments on financial markets.

6 Investors' need for information

The analyses of the physical and transition risks have mainly focused on primary and secondary effects of climate change as well as Scope 1 and Scope 2 emissions of investments in equity funds for reasons of data availability and reliability. However, further information should be available for a comprehensive detection of possible systemic financial market risks as well as risks for individual players such as information on tertiary effects, CO_2 data for investment classes beyond equity investments, data on Scope 3 emissions, i.e. emissions from the entire value chain, as well as analyses of corporate returns for different climate scenarios. The analysis of today's ways of pricing climate change also found a lack of information for financial market actors, in particular, future CO_2 prices. This shows that there is a need for more comprehensive information and analysis to enable investors to better understand climate change and to reduce the risks of climate change to financial stability.

Therefore, the focus of this chapter is on the information needs of investors in order to identify these risks related to climate change and to incorporate them into their investment decisions. There is a growing amount of literature to this end. The chapter first addresses literature that is relevant to investors. In a second step, the information currently accessible on the market is described. A comparison of the two perspectives leads to the third step: an analysis of the existing challenges for financial market actors.

6.1 Required information

Investors are increasingly aware of the importance of climate change. Which information is required and what level of detail always also depends on the objective and type of the investor. For this reason, it is first considered which investment classes are particularly important for each financial market operator. Based on this, it is described which level of information per asset class would be desirable according to literature research.

6.1.1 Financial market actors

An analysis, which information investors need to address climate risks in a meaningful manner should include, which investors are particularly relevant to the financial system, and which investments they are holding. The structure of the German financial market can be described as follows (Deutsche Bundesbank 2015a): monetary financial institutions, pension funds and insurance companies, open-end investment funds, and other financial intermediaries.

The German financial market is historically based on **banks** (Detzer 2012). This is also reflected in the holdings of financial assets: more than 60% of the financial assets in Germany are held by banks (Deutsche Bundesbank 2015a).

In 2014, the balance sheet totals of German banks amounted to EUR 7,802 billion (Deutsche Bundesbank 2016b). EUR 2,022 billion of which are cash flows to banks in the Euro Zone (75% of which were banks in Germany). Cash flows to enterprises, individuals, and public households accounted for 47% of the balance sheet total (EUR 3,655 billion). The majority of the balance sheet total is book loans (over EUR 5,100 billion, 2,385 billion of which are loans to domestic enterprises and private individuals), securities (equities and corporate and government bonds), and private equity amounted to EUR 1,358 billion. Significantly more than half of the total assets of banks, businesses, individuals, and public budgets (EUR 4,770 billion) are deposited domestically (Deutsche Bundesbank 2016b).

3.7% of the capital investments of German **primary insurers**, including **pension funds**, were invested in shares in 2014, predominantly in investment funds (GDV 2016a). Corporate bonds and government bonds accounted for 3.0 and 6.2%, respectively and direct loans to enterprises

1.0% and to governments 9.3%. Loans to banks (12.1%) and covered bonds, i.e. refinanced mortgages (19.8%) also make up a significant share of the investments.

The group of open-end investment funds comprises around one-third pure equity and bond funds, while approximately 45% are mixed securities funds (Deutsche Bundesbank 2015a). Bonds include corporate and government bonds. This is not unlike the situation at European level - here stocks and bonds account for more than 65% of assets (European Central Bank 2016).

A consideration of the information required by financial actors should therefore include:

- For banks information on loans and other banks,
- For primary insurers, pension funds included, on loans to governments and credit institutions as well as mortgages,
- And for investment funds for equity and bonds.

6.1.2 Typology of required information

The required information is obtained from the combination of the plurality of viewpoints (see Table 8).

The nature of the information depends primarily on the considered **climate risk** (physical risks or transition risks). Furthermore, there are different **aggregation levels** at which information can be provided. Information can be provided at the level of the individual physical investment, at the level of the companies, portfolios, and the financial market actor. This results in the aggregation levels.

As described in the previous chapter, certain **asset classes** are particularly relevant to certain financial market actors. For certain asset classes, the financial market needs similar information. For example, the underlying company and its physical assets are crucial for equities, bonds, and loans. The provision of the information specific to the respective asset class is, however, crucial for the use of information by investors (e.g. for integration into existing databases using the investment class-specific identification number, or because investment-class-specific analyses is based on the information). Therefore, this aspect is explicitly included in the overview.

There are also various **approaches to the assessment of climate risks**. Currently, emissions from companies are often used as an approximation. While these give an initial indication of risk factors in the portfolio, emissions data alone does not allow any assessment of the risk because it does not set the emissions in relation to potential losses or deviations of the company from a particular climate scenario. This is addressed, for example, by the Science Based Targets project. Guided by CDP, WRI, and WWF, it is currently developing a methodology that allows companies to set emission reduction targets consistent with a development pathway based on the 2° limit (Science Based Targets 2016b). Currently, more than 160 companies have committed themselves to such a goal (Science Based Targets 2016a).

Further methods as to how the climate-relevant behaviour of companies can be predicted up to 2020 and reconciled with international climate crises are, in addition to voluntary targets by companies, capital expenditure plans, and the extrapolation of past behaviour (2° Investing Initiative 2016a). Moreover, the importance of the strategic positioning of companies in the event of the occurrence of extreme weather events and particularly ambitious climate policy is emphasised (Zenghelis, 2016).

Previous publications on the question, which **data points** should ideally be available to investors to assess risks correctly, are from the Carbon Tracker Initiative (Carbon Tracker Initiative 2016) and the Climate Disclosure Standards Board (Climate Disclosure Standards Board in 2014) regarding companies in the fossil fuels field. They include a clear quantification of the ownership of fossil energy reserves, climate sensitivity analyses of facilities, details of long-term strategic positioning and capital investment plans (Climate Disclosure Standards Board 2014, Carbon Tracker Initiative 2016). Apart from fossil reserves, these data points can also be transferred to all other sectors.

The information summarized in Table 8 results from these different types of information. Real estate[74] and infrastructure play a special role and are therefore not listed separately. However, they play a role in project financing within the loans category. Due to their high real-economic relevance, they are also mentioned in the chapter on existing data sources.

[74] Investors are, among other things, exposed to the real estate sector in various ways through shares and corporate bonds of real estate companies as well as mortgages. Within the scope of this discussion, however, real estate is considered an asset class.

Table 8: Required information by asset class

Type of climate risk	Aggregation level	Data point	Asset class: Equities	Asset class: Corporate bonds	Asset class: Govt. bonds	Asset class: Loans
Physical risks	Individual facility/ country	– Investment-specific revenue and location – Climate sensitivity of the investment and upstream/downstream investments				X (for project loans)
	Securities/ debtor/ country	– Level of insurance and risk mitigation strategies – This also includes banks etc., i.e. financial market actors	X	X	X	X
	Portfolio	– Climate sensitivity based on stress test scenarios	X	X	X	X
	Sector	– Climate sensitivity based on stress test scenarios	X	X		X
Transition risks	Individual facility/ country	– Production costs and turnover, location – Size/capacity/production – Emission intensity				X (for project loans)
	Securities/ debtor/ country	– Capital investment plan – Climate Research & Development Expenditures – Market positioning – Emission intensity	X	X	X	X
	Portfolio	– Climate sensitivity based on stress test scenarios – Emission intensity	X	X	X	
	Sector	– Climate sensitivity based on stress test scenarios – Emission intensity	X	X		X

Source: South Pole Group, data points based on 2° Investing Initiative (2016a, 2016b)

6.2 Existing data sources and range of information

This chapter addresses the question of the range of information already available today. In addition, there is an overview of initiatives that develop new methods for additional data points. It also looks at the information already used by financial market actors. According to the expert interviews, all interviewed financial market players already take information on climate risks into account in one form or another.

6.2.1 Level of physical investments/projects

Physical risks

To assess the physical risks of a specific facility, ideally, its exact location would be available (see Table 8) so that it can be assessed according to its risk profile. This information is currently not publicly available. Insurance companies, however, often have detailed models for assessing such risks as soon as the geographic coordinates are provided. Under the "Climate & Economy" project financed by Climate-KIC, conducted by the Potsdam Institut für Klimafolgenforschung et al., the first data is now calculated more systematically. Moreover, existing insurance policies and their terms provide an indication of climate risks, as they are included in the price.

The expert interviews showed that in the case of project financing and real estate investments, physical risks of individual facilities and projects are considered as part of the routine feasibility analysis. However, an explicit climate perspective is not adopted.

For climate data and exposure regarding extreme events, information on individual countries is available about physical risks, for example in the form of climate fact sheets from the Climate Service Center (GERICS 2011). Munich Re maintains a database on damages from natural catastrophes, which is, according to interviews, also used by investors for project investments.

Transition risks

For some physical investments, databases are available which detail the service life and the used technology. Examples are the fuel and technologies used for each facility for utilities, the oil and gas production (GlobalData 2016), and the current and projected production volume of motor vehicles per drive technology (wardsauto 2016). Another supplier of data on facilities, for example for oil, gas, coal, petrochemicals, and metals, is Platts (Platts 2016). This data can be used to estimate transition risks. It is available in various formats and databases and only accessible for a fee.

For loans (for specific projects), real estate, and infrastructure investments, in addition to the above-mentioned physical risks, according to the expert interviews, transition risks are often included as part of the general analysis of possible risk factors. However, here, too, no systematic mapping of the risks from the climate perspective is provided.

The Investor Group on Climate Change (IGCC), together with the Australian National University, has published an overview report on the risks to property investments with a focus on Australia (Investor Group on Climate Change, Australian National University 2013). A similar publication is available from the Institutional Investors Group on Climate Change (Institutional Investors Group on Climate Change 2013), which is more focused on Europe. However, an application of the analysis to calculate the concrete financial impact of real estate portfolios or specific geographic regions is not provided.

6.2.2 Level of securities

Physical risks

Companies often perform qualitative risk assessments on physical risks associated with climate change, such as risks in the value chain. General information on physical risks, which are, however, based not on concrete physical investments nor companies, are made available by the Climate Service Center for Germany and parts of Europe

In the expert interviews, several actors also stated that the question of whether companies deal with the different climate risks and possible risk management is part of their evaluations.

There is also a growing, though still limited, number of publications on government bonds. In 2012, for example, UNEP FI, together with the non-governmental organization Global Footprint Network, published a report on the integration of environmental risks into the analysis of the creditworthiness of government bonds (UNEP FI, Global Footprint Network 2012). Furthermore, there are analyses on how extreme weather events influence the creditworthiness of states (Standard & Poor's 2015c, 2015d).

Transition risks

On the securities level, there is a range of data available, particularly for equities and corporate bonds. The organization CDP, for example, collects a wide range of information on how individual companies approach the issue of climate change. Using questionnaires, it identifies the opportunities and risks associated with climate change (CDP 2016a, 2016b). However, the individual responses are not reported separately but are summarized in an overall assessment. The individual aspects can thus not be considered separately.

Emission data from companies is provided by various suppliers, including the South Pole Group and Trucost. Several providers (including FTSE) also have databases on the sales of so-called “green” and “brown” technologies, i.e. those that are – with variations of the definition per provider – environmentally friendly or harmful.

Furthermore, there are a number of tailor-made reports and analyses that examine the effects of different transition scenarios on the securities level. Examples are an analysis of the impact of transition risks on the profit margin of companies exemplified by the cement sector (The CO-Firm 2015) and the Bloomberg Carbon Risk Valuation Tool, which considers the price performance of oil companies based on various oil price scenarios (Bloomberg 2013) and was also exemplified in this report (Chapter 4.1).

According to interviews, for example in the utilities sector, information on the general exposure to relevant aspects related to climate policy, such as the share of fossil fuels in electricity production, is included in decisions.

Analyses of government bond portfolios with regard to climate change are now made available by several providers, among others by a cooperation of the South Pole Group with the Global Footprint Network (Global Footprint Network 2015). In addition to determining the emission footprint of a government bond based on consumption or production data, the organization also provides analyses on the national fossil fuel reserves, the country’s political commitment to contribute to the 2° Celsius climate goal, and biocapacity surplus or deficit. In addition, Moody’s recently announced that it will also consider transition risks in the assessment of government bonds (Moody's, 2016), which means that the creditworthiness of states will also reflect information on transition risks in the future.

Both Moody’s and Standard and Poor’s have published reports analysing the impact of climate change on loans (Moody’s 2015, Standard & Poor’s 2015a, 2015c). These generally include both physical and transition risks associated with climate change.

6.2.3 Portfolio level

So far, there are few analyses that are able to make a statement on portfolio level. For shares and increasingly for corporate bonds, the generation of a carbon footprint has become a common practice. This is often considered as a first step to approach the subject.

Analyses, which examine portfolios across various asset classes, taking into account physical and transition risks, have so far been carried out “top-down”, i.e. globally aggregated. Reports were published by Mercer (2015), an institutional investment adviser, and the Cambridge Institute for Sustainable Leadership (CISL 2015). This type of analysis has so far been only made commercially available to investors by Mercer. The study explicitly includes real estate and infrastructure investments.

Another initiative, which focusses on the holistic recording of climate impacts of investment portfolios, is CLIMPAX. The project is developing a method for the valuation of equity fund portfolios (Climate-KIC 2016). Here, both emissions intensity and the orientation of companies towards the 2° Celsius limit play a role.

Given the limited data available, it is not surprising that the analysis of climate risks on portfolio level has not been highlighted by the interviewed experts.

6.2.4 Sector level

The sector is an essential variable for the assessment of climate risks and opportunities (Mercer 2015). The risk profile of a sector is determined, for example, by its emission intensity, the availability of low-emission alternatives to the current business model, and the dependence of the productive activity on weather conditions.

As described in Chapter 2.4, insurance, agriculture, forestry, oil and gas, energy supply, transport, commodities, and the industrial sector are particularly affected by physical and transition risks. This results in increased information requirements for investors to manage these risks.

At the sector level, a first risk analysis for all asset classes can often be carried out by the respective investor based on publicly available data. Data sources for assessing the risks of the different sectors include the published risk profiles of KPMG (KPMG 2008), Calter Investments together with Ceres and Oxfam (Calvert Investments, Ceres, and Oxfam 2012), Mercer (Mercer 2015), and Cambridge (CISL 2015).

The expert interviews also show that the sector is a very important analysis perspective. The sector of a company often determines whether an in-depth analysis is carried out with regard to climate risks.

6.3 Challenges and data gaps

The available information on climate change is currently characterised by a number of challenges and gaps. Firstly, there are gaps in the coverage of different asset classes and aggregation levels. Secondly, the fragmented market for information as well as missing standards represent challenges.

6.3.1 Asset class, aggregation level, and methods

Asset class

Many of the reports published to date focus on the perspective of investors in corporate bonds and shares. This perspective, however, is particularly relevant to investment funds and only parts of the portfolios of other financial market actors. Government bonds have only recently been taken into account and loans are still barely covered.

Thus, a comprehensive analysis of not only certain asset classes is missing, but also the perspective of important financial market actors, such as banks, especially in connection with loans.

The efforts of the Task Force on Climate-Related Financial Disclosure, which also focuses on the reporting of financial institutions, are interesting in this respect. In this context, loans and the insurance business are explicitly mentioned as well as the disclosure of climate risks at the level of the financial institution as a whole in order to draw conclusions on the financial system (TCFD 2016).

Real estate and infrastructure investments are not taken into account in the overview because investors are often not invested directly in such projects, but through large companies, project developers, and banks.[75] Nevertheless, they are important for the financial market due to several factors: they have a high real economic importance, they are exposed to climate risks due to their long durations, and because of their (often) higher illiquidity, investors have less room for manoeuvre to react to such risks in the short term.

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[75] 38% of direct private investments in climate-friendly projects were made by project developers, 24% by corporations, and 19% by commercial financial market actors (Climate Policy Initiative 2015).

In real estate and infrastructure investment, climate risks are covered within the overall feasibility study, but not in the form of a systematically applied climate risk analysis. For investors in real estate or infrastructure funds, or dedicated real estate companies, however, this information is mostly not accessible or not accessible in a structured manner.

Aggregation level

While climate risks are increasingly considered at the level of companies or states, little information has been made publicly available at the level of the individual facility (i.e. differentiated by the location of different production facilities or at the level of the project). This analysis perspective would be a valuable addition, as it would allow a detailed bottom up assessment of risks. A fragmented data landscape is, however, currently hindering the implementation: for most subsectors, there are separate data providers. And while this level is a relevant basis, the analysis of individual facilities cannot be used by investors, except in the case of direct project investments as they require an assessment of the entire company.

Methods

Currently, more and more methods are being developed to capture transition risks. An important aspect of this is the question of metrics to determine the orientation of investments towards a 2° Celsius limit. This is particularly relevant in the context of the Paris Climate Agreement. Although this perspective is not the focus of this report, it is mentioned for the sake of completeness, since a stronger orientation of an investment towards the 2° Celsius limit implies lower transition risks. Here too, a series of initial methods are available for equities and corporate bonds. Other investment classes have so far barely been covered (2 ° Investing Initiative, 2016a).

6.3.2 Harmonization of data and processes for data use

As demonstrated in the previous chapter, the current information landscape on climate change is highly fragmented. An investor who wants to get an overview of the climate risks of his investments must turn to a number of different providers. There is no central point of contact.

Currently, the compilation of relevant information for equities and corporate bonds is the easiest to acquire. A report from the 2° Investing Initiative (2016a), published in May 2016, proposes, for example, a combination of different sources, which corresponds to reporting to the most comprehensive extent possible. The focus here is strongly on equities and corporate bonds. The cost of such a report is estimated to be EUR 20,000 to 50,000.

This shows that besides the fragmentation of the information the costs of such data points can represent a hurdle. Moreover, comparability of the data is not always possible due to missing standards. This concerns, on the one hand, the metrics of the data. For this reason, the Swedish pension funds decided on common multilateral standards for reporting the emission footprint of their portfolios in November 2015 (AP Funds 2015).

On the other hand, the lack of comparability also affects the scenarios used for the execution of stress tests. Differing assumptions regarding the amount, the extent, and the time of physical damage, or the occurrence of transition risks can lead to substantial differences in the analysis results. Other technical aspects such as discounting factors also have a significant influence on the results. The Energy Transition Risk project (University of Oxford, 2° Investing Initiative, et al., 2016) an initiative supported by the European Commission, addresses the problems for transition risks of equities and bonds. Insurance companies could play a similar role as a data aggregator for physical risks.

Beyond the standardization of data, the development of meaningful processes is also important. Data must be made available in a way that allows easy use by financial market actors, e.g. through integration into existing processes. Furthermore, the question arises as to how exactly the data is incorporated into decisions. The Task Force on Climate-Related Disclosure is addressing the second aspect in particular under a separate work package (TCFD 2016).

6.4 Conclusions

In theory, there are clear ideas as to what information is typically needed to assess the risks to investors in the context of climate change (see Table 8).

In practice, however, not all the information required appears to be available, either because it is not available at all or not sufficiently standardized. Regarding the time horizons, it should be noted that by 2020, information on existing technologies and regulations can be made available. From 2020, the consideration of scenarios is central.

In general, there is great uncertainty about two pieces of core information: the physical impact of climate change at company level and the likelihood and design of 2° Celsius-compatible regulatory interventions. Even the Paris Agreement has failed to provide a clear picture and many investors today do not expect the 2° Celsius-target to be implemented politically. The need for more consistent and realistic signals on the part of policy makers towards a transition path to a low-carbon economy (with information on sectors and technologies) was also emphasized in a recently published study by the Dutch Central Bank (Schotten et al., 2016).

At the same time, there is an increasingly broad availability of data on CO_2 emissions and other data on transition risks, especially for equities and corporate bonds. However, this is characterized by a high degree of fragmentation, and analyses are often only available in the context of tailor-made projects.

Standards, both for data provided by companies as well as the various scenarios for performing stress tests, can simplify integration into existing investment processes and IT systems and create comparability. However, as there are a growing number of analysis perspectives, few of them result in an explicit quantification of the financial risk.

7 Conclusions

Physical risks of climate change

Overall, it is very unlikely in the short and medium term that a risk to financial market stability in Germany and Europe could develop as a result of the physical effects of climate change. Direct physical risks (primary effects) exist primarily for the insurance industry due to higher and more variable weather damage. It can, however, adapt relatively well to direct risks, since insurance premiums can be adjusted on an annual basis, and the technical reserves can be adjusted continuously. Today, the German insurance industry has significantly more risk capital than necessary to meet the legal requirements to cover company-wide losses that occur only every 200 years. Ongoing adjustment of the risk capital provided, defaults due to extreme events are very unlikely. However, instability in case of a surprise effect caused by several, very unlikely and particularly damage-intensive extreme events within a year cannot (as in the case without climate change) be ruled out.

Secondary effects can be caused by non-insurance against severe weather-related losses. This is currently not a relevant risk for financial investors in Germany since almost 100% of the larger companies are insured against all major weather risks. However, with increasing damage due to climate change, certain natural catastrophe risks could no longer be insured as premiums become too expensive. Extreme events could weaken the balance sheets of uninsured companies and households, thus increasing the default risk. This would also lead to the risk of reduced lending, but this is only a significant risk when the insurance penetration is low, and if the ability of a state to set up relief programs for injured companies and households in extreme events is limited. Such massive indirect risks, which would lead to a downgrade of a country,s creditworthiness, exist only in certain smaller countries and low-income countries, and are very low for the German financial market, as it is hardly invested in bonds or shares of such countries. Chronic damage due to climate change is not a relevant risk to financial market stability in Germany due to its gradual development (a maximum of 0.01 to 0.1% reduction in GDP per year).

Physical risks will increase with ongoing global warming and the international interdependence of the German economy, e.g. through value chains and sales markets.

Transition risks

Primary effects are only marginally relevant because of the low own GHG emissions od financial market actors. Transition risks have a more important impact on the financial market through the investment of German financial market actors in companies affected by transitions risks (secondary effects). Companies can, for example, be affected by the introduction of a CO_2 tax, the EU or other existing emissions trading systems,stricter regulation of energy efficiency or a decrease in the demand for emission-intensive products (e.g. cars). The potential magnitude of transition risks can be estimated using CO_2 price scenarios or assumptions about the general depreciation of investments in certain industries.

If equity funds examined under this study had to bear their financed emissions in the oil and gas, energy, commodities, and industrial sector, this could lead to costs of up to EU 4 billion, representing 4.5% of the asset value in these sectors and 1.2% of the total investment value of these funds. However, equity funds only represent a fraction of the financial market. Under the high level assumption that, based on the high level of integration of the financial market with the general macroeconomic development, the economic costs of climate change amounting to approximately 2-5% of the GDP (magnitude for both Germany and worldwide) also are applicable for the financial market, losses of EUR 262 to 655 billion can be expected in the German financial market due to climate-related transition risks.

It is difficult to assess the probability of the occurrence of such losses and how suddenly such a shock might occur, since this depends, i.a., on the probability and predictability of regulation in

Germany and other countries. The above figures thus represent an extreme scenario of maximum potential losses in a short period.

Transition risks of up to 2-5% of the financial market alone are very likely only to present a low risk to the stability of the financial market, especially considering historical volatilities of up to 5-15% in the stock market per day and very low probabilities of a single-day transitional shock. However, the secondary effects analysed could lead to problematic effects for financial stability, in case of high interdependence of financial players and low overall stability of the systems. Such combined effects depending on the state of the financial system, are not yet well understood.

Pricinf climate risks

Today,s pricing of CO_2 in the German financial market focuses on longer-term investments as well as actors with high CO_2 emissions, especially in the energy and industrial sector. The level of the pricing should optimally be based on realistic expectations regarding future, regulatorily influenced CO_2 prices. However, it cannot be conclusively assessed whether the current level of pricing is actually based on realistic expectations since there are no standardized scenarios of future regulations. Today,s carbon pricing (if there is any) is based on today,s CO_2 market prices and is therefore significantly lower than the social costs of CO_2 emissions. This can lead to a risk to financial stability: if policy makers direct CO_2 prices towards social costs of carbon within a short time (by means of taxes, quantitative restrictions or other measures), the result is a transition shock, as such high costs were not included in the valuation of investments and therefore many investments could suffer significant losses in value.

Physical climate risks are barely factored in outside of the (re-)insurance industry due to the complexity and the not yet significantly rising climate-related losses. Financial institutions and smaller insurers rely on pricing as well as the knowledge of larger insurance companies, in particular reinsurers. Such large insurance companies rely on historical-statistical data for weather-related losses for pricing physical risks, they do not actually use projections on climate change for their risk management.

Information required by the financial market

In theory, there are clear ideas about what information would be required, so investors can properly assess and price risks associated with climate change. In practice, however, not all the information required is easilty at hand for financial players, either because it is not available at all or because it is not sufficiently standardized.

In general, there is great uncertainty about two core pieces of information: the longer-term physical effects of climate change and the likelihood and design of 2°-compatible regulatory interventions. Even the Paris Agreement has failed to provide a clear picture of future CO_2 prices. Many investors today do not expect the 2°-target to be implemented politically. The need for more consistent and realistic signals on the part of policy makers towards a transition path to a low-carbon economy was also emphasized in a recently published study by the Dutch Central Bank (Schotten et al., 2016).

For equities and corporate bonds, there is an increasingly broad database regarding CO_2 emissions and potential losses in value resulting from climate policy, but data is highly fragmented. Uniform standards are missing for both the data provided by companies as well as the analysis of the financial impact of different scenarios. Moreover, in-depth analyses, e.g. about the extent to which profit margins are endangered by climate change, are often available only in the context of tailor-made projects.

Data standards could simplify the integration of data into existing investment processes and IT systems, and the development of uniform scenarios for scenario analyses would create comparability. Although there are a growing number of analysis on transition risks, few of them lead to an explicit quantification of the *financial* risk.

Recommendations

Based on the results of this study, the following is recommended to manage **physical risks**:

- Promoting the dialogue between policy makers, the insurance industry, and the financial market on how to deal with very unlikely, but particularly damage-intensive extreme events.
- Discussion on an international level (e.g. within the framework of the Financial Stability Board) regarding the possibilities and benefits of a coordinated, standardised measurement of physical risks, which can also be used as a basis for a possible climate stress tests.

Based on the results of this study, the following is recommended to manage **transition risks**:

- Reliable policy signals on how quickly and with which CO_2 prices the transition to a low-carbon economy is planned. The Carbon Leadership Coalition of the World Bank could contribute to this. An abrupt change in climate policy is to be avoided. Reliable long-term policy signals with a focus on CO_2 pricing have also been recommended in a study conducted by the Dutch Central Bank (Schotten et al., 2016).
- Support of the implementation of data and measurement methods for asset classes beyond publiy equity, in particular, corporate bonds, government bonds, loans, and real estate/mortgages.
- Discussion on an international level (e.g. within the framework of the Financial Stability Board) on the possibilities and benefits of coordinated, standardised scenario analyses of transition risks, which can also be used as a basis for a possible climate stress test. The need for standards has also been emphasized in a study by the Dutch Central Bank (Schotten et al., 2016)

To close gaps in **research on climate risks**, we also recommend:

- In-depth analyses of potential tertiary effects, especially the interdependence of financial market actors who are invested in fossil fuels.
- Studies of insufficiently studied asset classes, for which climate risks are of particular importance, especially corporate bonds, government bonds, real estate, loans, and investment in agriculture.
- Studies on sectors with significant emissions in the upstream and downstream value chain (e.g. automotive sector, food sector).
- In-depth studies on the interdependence of the German real economy and finance industry with physical risks and their political and economic consequences in regions that are more affected by climate change (e.g. Bangladesh, Thailand, and Sub-Saharan Africa).

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Appendix I

The advisory committee of the study is composed as follows:

- Prof. Peter Höppe, Head of Geo Risk Research/Corporate Climate Centre, Munich Re. His areas of expertise include the evaluation of environmental risks.
- Prof. Wolfgang Härdle, Director of the Ladislaus von Bortkiewicz Chair of Statistics, Faculty of Business and Economics, Humboldt University, Berlin, expert in the modelling of financial markets
- Dr. Oliver Schenker, Assistant Professor of Environmental Economics at the Frankfurt School of Finance & Management, specific expertise on international climate policy and cross-border effects of regional climate problems (via trade and value chains)
- Axel Wilhelm, Sustainable Investments & Environmental Officer, Concordia Versicherungs-Gesellschaft, expert for sustainable investment
- Prof. Andreas Levermann, Professor for the dynamics of the climate system, Potsdam Institute for Climate Impact Research (PIK) - expert in the field of global adaptation strategies and climate impact for the global infrastructure and supply network
- Dr. Daniela Jacob, Director of the Climate Service Center Germany Climate Service Center 2.0, Institution at the Helmholtz Center Geesthacht & Max Planck Institute for Meteorology, Hamburg, expert for climate change, water circulation, and floods
- Prof. Hermann Lotze-Campen, Head of PIK Research Division II "Climate Impact and Vulnerability", Professor for sustainable land use and climate change, Humboldt University, Berlin, expert on the agrarian-economic effects of climate change
- Prof. Dr. Valerio Lucarini, Professor of geosciences, University of Hamburg - expert in weather and climate studies

Appendix II

Consulted and interviewed experts:

- Dr. Urs Bitterling, Head of ESG Office, Allianz Group
- Karsten Löffler, Managing Director, Allianz Climate Solutions
- Axel Wilhelm, Sustainable Investments & Environmental Officer, Concordia Versicherungs-Gesellschaft
- Johannes Behrens-Türk, Head of Sustainability Management DekaBank
- Susana Peñarrubia, Director, Deutsche Asset Management (DWS)
- Martin Berg, Senior Investment Manager, European Investment Bank
- Oliver Hauner, Head of property and technical insurance, damage prevention, statistics, German Insurance Association - Gesamtverband der Deutschen Versicherungswirtschaft (GDV)
- Dr. Bernhard Gause, Member of the management board, GDV
- Dr. Olaf Burghoff, Head of Statistics and Modeling Natural Hazards, GDV
- Tim Ockenga, Head of investments, GDV
- Dr. Karl Ludwig Brockmann, Chief Officer Environment and Sustainability, KfW Group
- Ernst Rauch, Head of Corporate Climate Center, Munich Re.
- Dr. Reiner Sachs, Head Group Accumulation / Emerging Risk, Munich Re.
- Michael Bentelage, Head of Structuring in the Capital Partners division (alternative risk transfer); Munich Re
- Matthias Stapelfeldt, Head of Sustainability Management, Union Investment
- Dr. Thomas Deser, Senior Portfolio Manager Equities, Union Investment

south pole group

Appendix III

List of analysed equity funds

Sample 1: Largest equity funds approved for distribution in Germany (sorted by total fund size)

M&G Global Dividend Fund
BlackRock Developed World Index
Fidelity Funds - European Growth
Vanguard Global Stock Index Fund
Templeton Growth (Euro) Fund
DWS Vermoegensbildungsfonds I
Allianz Europe Equity Growth
Carmignac Investissement
BGF European Fund
MFS Meridian Funds-European Value Fund
Newton Global Income Fund
MFS Investment Funds-Global Equity Fund
JPM Europe Equity Plus
MFS Meridian Funds-Global Equity Fund
Morgan Stanley Global Brands
Vanguard European Stock Fund
Allianz European Equity Dividend
Schroder ISF Global Dividend Maximiser
BGF World Mining Fund
DWS Akkumula
Deutsche Invest I Top Dividend
SKAGEN Global
JPM Europe Strategic Dividend
Pictet-Global Megatrend Selection
BGF European Equity Income Fund
BGF World Healthscience Fund
JPM Global Healthcare
Robeco
Fidelity Funds - Global Dividend
M&G Global Basics Fund
Newton International Growth Fund
Pictet-Water
Franklin Mutual European Fund
JOHCM Global Select Fund
BGF European Value Fund
AriDeka CF
BGF World Gold Fund
BGF European Focus Fund
BGF Global Equity Income Fund
UNI-GLOBAL Equities Europe
Russell World Equity Fund

Threadneedle Global Equity Income Fund
SEB Global
Best Global Concept
JPM Global Focus
Threadneedle Pan European Smaller Companies Fund
Comgest Growth Europe
Parvest Equity Best Selection Europe
BGF World Energy Fund
Odey Allegra International Fund
Nordea 1 - Global Stable Equity Fund - Unhedged
Jupiter European Growth
Oddo Avenir Europe
Pictet-Europe Index
Fidelity Funds - International
PARVEST Equity Europe Small Cap
UBS (Lux) Inst Fd - Key Sel Global Eq
JPM Europe Dynamic
JPM Europe Strategic Value
Pioneer Funds Top European Players E
Pioneer Funds European Potential
DWS Top World
Baring Europe Select Trust
Investec GSF Global Franchise Fund
Janus Global Life Sciences Fund
Schroder ISF European Dividend Maximiser
Pictet-Biotech
Deka-DividendenStrategie
MFS Meridian Funds-European Research Fund
Schroder ISF QEP Global Active Value
Aberdeen Global - World Equity Fund
Nordea 1 - European Value Fund
Industria
Old Mutual Voyager Global Dynamic Equity Fund
Schroder ISF QEP Global Quality
Investec GSF Global Strategic Equity Fund
M&G European Strategic Value Fund
JPM Europe Select Equity
BNY Mellon Long-Term Global Equity Fund
KBC Equity Fund Strategic Finance
Deka-BR 100
Morgan Stanley Global Quality Fund
Dimensional Funds PLC Global Targeted Value Fund
Vontobel Fund Global Equity

Templeton Global Fund
Russell Investment Company World Equity II Fund
Robeco BP Global Premium Equities B EUR
Robeco Global Consumer Trends Equities
UBS (Lux) KSS 2 - Global Quantitative (USD)
KBC Equity Fund Strategic Cyclicals
BGF European Special Situations Fund
DWS Top 50 Europa
Echiquier Major
Franklin Mutual Global Discovery Fund
DJE - Dividende & Substanz
KBC Equity Strategic Satellites
Robeco European Conservative Equities
AXA WF Framlington Europe
Dimensional Funds PLC Global Core Equity Fund
Generali Komfort Dynamik Europa

Sample 2: Equity funds issued by German asset management companies of systemically relevant banks (sorted by total fund size)

LBBW Dividenden Strategie Euroland
LBBW Exportstrategie Deutschland
LBBW Aktien Europa
LBBW Aktien Deutschland
LBBW Zyklus Strategie
LBBW Dividenden Strategie Small & MidCaps
LBBW Rohstoffe & Ressourcen
LBBW Nachhaltigkeit Aktien
LBBW Global Warming
DekaFonds
AriDeka CF
Deka-DividendenStrategie
Deka-BR 100
Deka-Europa Aktien Spezial
DekaLuxTeam-GlobalSelect
Deka-EuroStocks
DekaLux-Deutschland
DekaLux-Europa
Deka-EuropaSelect
Deka-TeleMedien TF
DekaLuxTeam-EmergingMarkets
DekaSpezial
Deka-Euroland Aktien LowRisk
DekaLux-PharmaTech
DekaLux-USA

DekaLux-BioTech
Deka-Technologie
Deka-Globale Aktien LowRisk
Deka-ConvergenceAktien
Deka-Europa Potential
Deka-GlobalChampions
Deka-bAV Fonds
Koeln-Aktienfonds Deka
Deka-UmweltInvest
DWS Vermoegensbildungsfonds I
DWS Deutschland
DWS Akkumula
Deutsche Invest I Top Dividend
DWS Investa
DWS Aktien Strategie Deutschland
DWS Top World
DWS Top Asien
Deutsche Invest I Top Euroland
DWS Top 50 Europa
DWS European Opportunities
Deutsche Invest I Global Infrastructure
Deutsche Invest I Global Emerging Markets Equities
Deutsche Invest I German Equities
DWS Eurovesta
DWS Global Growth
DWS Top Dynamic
DWS Biotech
Basler-Aktienfonds DWS
DWS Health Care Typ 0
DWS German Equities Typ O
Deutsche Invest I Emerging Markets Top Dividend
DWS Telemedia Typ O
Deutsche Invest I Top Asia
Deutsche Invest II US Top Dividend
1. SICAV European Advice Equities
HI-DividendenPlus-Fonds
HI-DividendenPlus Europa-Fonds
SEB Global
SEB Aktienfonds
SEB Global Chance/Risk
SEB Concept Biotechnology
SEB 1 Europe
SEB Listed Private Equity C EUR
SEB Nordic
SEB Europafonds

Method: Financed emissions

The emission data for a company used here comprises the areas 1 (own emissions) and 2 (emissions from the electricity consumption).[76] The database developed by South Pole Group together with scientists from the ETH Zurich is used as a basis for estimating the corporate emissions underlying the financed emissions. For analysis, the yourSRI carbon footprinting software was used. The data sources include (1) company reports (CSR, integrated reports), (2) the CDP (former Carbon Disclosure Project) database, and (3) other direct and indirect information such as company websites and investor relations documents. For all companies that do not report data, (4) approximation models are used.

The 100 largest equity funds (based on total fund size) approved for distribution in Germany are examined as a sample.[77] Since many of the largest funds approved for distribution in Germany are not issued by German asset management companies, these 100 funds have been supplemented by 61 equity funds of asset management subsidiaries of systemically relevant German banks.[78]

Approximately 61% of the companies surveyed publish their CO_2 emissions. Emissions for companies that do not provide their own figures have been estimated using econometric models as described above.

[76] Scope 1 are direct greenhouse gas emissions of a company, e.g. those caused by production processes. Scope 2 refers to indirect greenhouse gas emissions through energy consumption (electricity and heat). Scope 3 covers the remaining indirect greenhouse gas emissions. Examples are emissions along the supply chain, during product use, or business travel.

[77] Such German banks were qualified as systemically relevant banks, which are under supervision of the ECB.

[78] A statistic, which percentage of the money comes from Germany, was not included due to lack of data availability.

Investments of the examined sample in the oil and gas industry

Table 9: Oil and gas industry subsectors with portfolio weighting and associated financed emissions

Sector	% of the portfolio	Total invested capital (EUR)	Financed annual emissions (tCO_2e)	% of emissions financed by equity funds
Exploration & production	1.24%	4,062,443,244	4,441,822	9.35%
Integrated oil & gas	2.78%	9,101,711,966	4,242,386	8.93%
Oil equipment & services	0.70%	2,284,915,747	205,480	0.43%
Pipelines	0.24%	797,230,806	468,694	0.99%
Total	**4.97%**	**16,246,301,764**	**9,358,381**	**19.71%**

Source: South Pole based on South Pole Group, yourSRI and Thomson Reuters

Carbon Underground 100 Oil and Gas

Table 10: Investments of the examined sample in the Carbon Underground 100 Oil and Gas

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Gazprom	1	44.130	29,066,203	28,897,286
Rosneft	2	13.372	2,028,442	5,544,611
PetroChina	3	8.596	2,165,326	56,362,452
ExxonMobil (Hess)	4	8.128	14,798,584	592,027,807
Lukoil (US GAAP)	5	7.061	3,368,979	12,965,050
BP Plc. (Hess)	6	6.546	85,162,908	1,258,267,281
Petrobras	7	5.444	19,867,539	93,492,813
Royal Dutch Shell	8	4.209	71,801,222	2,524,411,785
Chevron Corporation (Hess)	9	4.036	11,772,390	494,567,242

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Novatek	10	3.875	1,193,583	7,527,756
Total (Hess)	11	3.771	30,751,316	901,921,324
ConocoPhillips (Hess)	12	2.782	9,490,550	196,260,929
Tatneft	13	2.551	883,943	3,265,681
ENI	14	2.377	19,247,112	443,161,616
ONGC	15	2.371	34,745	452,720
Statoil ASA	16	1.915	22,134,231	517,278,102
Sinopec	17	1.657	419,761	22,452,847
CNOOC Ltd	18	1.559	3,625,693	109,826,480
BG Group	19	1.246	21,993,028	887,011,420
Canadian Natural Resources Limited	20	1.109	2,206,440	47,522,163
Occidental Petroleum Corporation	21	1.083	4,594,157	217,147,296
Anadarko Petroleum Corp.	22	1.009	9,554,368	232,809,999
Bashneft	23	0.944	143,912	610,130
EOG Resources	24	0.919	5,207,788	219,974,301
Apache Corporation	25	0.879	6,715,472	129,404,154
Inpex Corporation	26	0.871	4,125,069	68,060,710
Devon Energy Corporation	27	0.837	7,554,464	115,036,727
Chesapeake Energy Corp.	28	0.828	20,590,639	72,749,590
Ecopetrol	29	0.813	93,591	1,655,791
Repsol	30	0.761	8,532,223	176,361,879

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Suncor Energy Inc.	31	0.693	2,833,723	152,243,693
Marathon Oil Corp.	32	0.688	12,142,378	147,869,983
Antero Resources Corporation	33	0.680	205,139	1,797,095
Imperial Oil Limited	35	0.626	230,506	10,104,901
Southwestern Energy Co.	36	0.589	11,481,843	47,209,407
Noble Energy	37	0.582	5,047,353	119,670,109
EQT Corp	38	0.578	780,107	10,582,474
Hess Corp	39	0.559	2,710,739	66,838,028
Range Resources Corp	40	0.546	6,316,184	44,905,547
Continental Resources	41	0.525	305,885	4,832,567
Wintershall	42	0.483	11,907,112	1,748,697,664
Encana Corporation	43	0.452	7,334,136	66,309,195
Cabot Oil & Gas Corp.	46	0.408	4,394,273	75,737,184
OMV	47	0.406	1,931,259	44,425,983
Cenovus Energy Inc.	48	0.380	355,859	9,779,770
KazMunaiGas Exploration Production	50	0.347	3,817,901	31,303,690
Husky Energy Inc.	51	0.336	172,068	5,131,247
Woodside Petroleum	52	0.331	1,118,519	58,459,982
Whiting Petroleum Corporation	53	0.313	2,068,998	11,655,233
Ultra Petroleum Corporation	54	0.301	5,206,423	6,461,595

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
California Resources Corporation	55	0.297	451,149	1,172,640
PTT	56	0.287	77,490	5,216,937
Pioneer Natural Resources Company	57	0.286	1,360,858	88,413,035
SK Innovation Co. Ltd	58	0.263	2,774	107,816
Murphy Oil Corporation	59	0.261	2,631,025	38,045,870
Sasol Limited	60	0.247	176,806	12,726,452
WPX Energy	61	0.245	323,223	1,875,642
Concho Resources Inc	62	0.244	367,223	17,795,415
EP Energy Corporation	63	0.233	153,902	675,988
Newfield Exploration Company	64	0.231	124,743	2,815,184
QEP Resources Inc	65	0.229	159,304	1,608,570
Crescent Point Energy Corp	66	0.197	680,364	20,088,572
Santos	68	0.193	194,495	4,890,382
SM Energy Company	69	0.188	512,204	3,367,694
SandRidge Energy	71	0.181	279,804	152,261
Cimarex Energy Co.	72	0.179	1,676,246	79,346,140
Denbury Resources Inc.	73	0.178	316,155	1,243,242
MEG Energy Corp.	74	0.175	359,761	2,567,042
Tourmaline Oil Corp.	81	0.143	271,995	6,648,232
MOL	82	0.140	40,294	1,491,698

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Energen Corp	83	0.137	689,010	16,083,633
Penn West Petroleum Ltd.	84	0.127	97,607	330,908
Polish Oil & Gas	85	0.127	63,766	3,907,036
JX Holdings Inc	86	0.124	84,064	7,104,304
Pacific Exploration and Production Corporation	87	0.122	108,318	322,683
ARC Resources Ltd.	90	0.116	254,545	9,052,656
Oasis Petroleum Inc.	91	0.112	80,301	681,291
Peyto Exploration & Development Corp.	93	0.106	143,433	3,827,582
Oil Search	95	0.105	673,732	47,796,704
Genel Energy Plc	96	0.101	728,488	4,983,267
Galp Energia	98	0.096	1,325,597	135,385,498
Canadian Oil Sands Limited	99	0.095	2,597,898	78,808,237
Total	**82**	**151.264**	**516,490,653**	**12,699,575,900**

Source: Fossil Free Indexes, South Pole Group

Carbon Underground 100 Coal

Table 11: Investments of the examined sample in the Carbon Underground 100

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Coal India Limited	1	43.111	253,166	179,794
Adani Enterprises Limited	2	27.809	18,422,286	914,387
China Shenhua Energy Company Limited	3	23.231	30,454,211	57,127,360
China Coal Energy Company Limited	4	13.095	1,462,829	1,141,345
Glencore Plc	5	11.416	297,009,051	498,610,470
Peabody Energy Corporation	6	9.872	16,735,595	252,326
Exxaro Resources Limited	7	9.430	56,696	6,304
Public Power Corporation S.A.	9	9.339	16,246,816	1,594,115
Yanzhou Coal Mining Company Limited	10	8.958	37,411	22,260
BHP Billiton Group	11	7.338	14,292,934	128,811,946
Inner Mongolia Yitai Coal Company Limited	12	6.240	31,253	13,860
PT Bukit Asam (Persero) Tbk.	13	5.310	54,615	7,735
Evraz Plc	14	5.035	32,742,449	9,585,211
Mitsubishi Corporation	15	4.878	4,474,815	24,524,504
Anglo American Plc	18	4.353	72,041,101	95,496,325
Arch Coal, Inc.	20	4.061	4,894,366	23,791

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Jindal Steel & Power Limited	22	3.596	20,665	7,505
Rio Tinto	23	3.584	63,088,173	946,303,645
China Cinda Asset Management Corporation	24	3.409	193,276	771,700
Vale SA	25	3.385	12,383,077	57,999,553
PAO Severstal	26	3.220	446,216	963,468
Westmoreland Coal Company	29	2.805	364,403	13,540
Tata Steel Limited	31	2.643	15,339	21,945
Teck Resources Limited	32	2.625	80,739,558	68,181,440
AGL Energy Limited	36	2.144	2,283,963	9,400,534
PT Adaro Energy Tbk	37	2.040	21,442	12,491
Cloud Peak Energy Inc.	39	1.848	1,868,987	126,201
Sasol Ltd	40	1.823	1,305,924	12,726,452
Whitehaven Coal Limited	41	1.769	1,019,133	301,371
Alliance Resource Partners, L.P.	43	1.561	1,102,107	705,558
NACCO Industries Incorporated	44	1.527	802,114	157,538
Open Joint Stock Company Novolipetsk Steel	45	1.481	341,974	1,179,613
New Hope Corporation Limited	46	1.453	165,891	125,801
PGE SA	49	1.386	1,783,152	7,885,951

Company	CU100 rank	Total potential reserves (G tCO_2)	Financed potential emissions (tCO_2)	Invested capital (EUR)
Matra Eromu ZRT (RWE Power)	58	0.963	6,112,549	49,085,027
ITOCHU Corporation	59	0.958	1,136,593	23,592,515
Mongolian Mining Corporation	60	0.942	589,594	131,614
ArcelorMittal	63	0.876	5,906,337	48,652,204
Wesfarmers Limited	66	0.847	587,275	23,865,236
Up Energy Develop-ment Group Limited	67	0.826	103,149	32,524
CONSOL Energy Inc.	69	0.774	2,210,776	5,092,318
PT Indo Tambangraya Megah Tbk. (Banpu)	70	0.770	298,762	181,080
ALLETE, Inc.	73	0.723	30,011	104,961
Energy Australia	80	0.552	455,894	17,714,080
White Energy Company Limited	81	0.547	83,348	5,100
Hallador Energy Company	82	0.537	31,500	8,082
TECO Energy, Inc.	83	0.536	19,439	228,732
African Rainbow Minerals Limited	86	0.522	28,324,011	32,533,068
Vedanta Limited	88	0.515	4,653	37,064
Southern Copper Corporation	90	0.496	3,108,259	129,567,942
Mitsui & Co., Ltd.	94	0.475	1,037,008	47,044,669
Total	**51**	**247.633**	**727,194,146**	**2,303,072,255**

Source: Fossil Free Indexes, South Pole Group

Examined companies within the scope of Chapter 4

Table 12: Top 5 "integrated oil & gas" companies based on total capital invested

Company	% of the portfolio	Total invested capital (EUR)	Financed annual emissions (tCO_2e)
Royal Dutch Shell PLC ORD	0.772%	2,524,411,785	1,106,862
BP PLC ORD	0.385%	1,258,267,281	655,066
Total SA ORD	0.276%	901,921,324	389,324
BG Group PLC ORD	0.158%	517,278,102	169,269
Total	**1.772%**	5,793,906,300	**2,525,332**

Source: South Pole Group, yourSRI, Thomson Reuters

Examined scenarios within the scope of Chapter 4

Table 13: Potential share price developments - Scenario overview

Scenario	Description
Scenario 1 - 5% annual decline in the oil price from 2020	From 2020 onwards continuous decline in the price of oil by 5% compared to forward transactions, as the regulatory interventions continue to intensify
Scenario 2 - USD 50/barrel of oil from 2020	From 2020, constant oil price at a level of USD 50/barrel of oil.
Scenario 3 - USD 25/barrel of oil from 2030 onwards	From 2030 constant oil price of USD 25/barrel, since stronger regulatory interventions will only take place from 2030 onwards.
Scenario 4 - Direct decarbonation	Reduction of the EBIT of oil companies by 80% by 2020, based on the assumption that 80% of the reserves are not exploited in order to reach the 2° Celsius climate goal.
Scenario 5 – Last minute decarbonation	Reduction of EBIT by 80% from 2030 onwards.

Source: Bloomberg (2013)

Calculations on emissions from housing loans and potentially resulting costs

Table 14: Statistical base of the potential costs of a CO_2 price on emissions associated with housing loans

Data basis				
Index	**Data point**	**Value**	**Unit**	**Source**
(1)	Housing loans for domestic enterprises and individuals	1218.5	billion EUR	Deutsche Bundesbank 2016a
(2)	Average housing prices Germany	2613.07	EUR/m^2	Immowelt 2016
(3)	living space-related overall energy consumption of the building stock	169	kWh/m^2a	BMWI 2014
(4)	CO_2- emission factor gross national electricity consumption	595	gCO_2eq/kWh	UBA 2014
(5)	Effective annual interest rate of housing loans for households (Sept.)	2.07	% p.a.	Deutsche Bundesbank 2016c
(6)	Price scenario 1	6	EUR/tCO_2	Global Environmental Exchange 2016
(7)	Price scenario 2	99	EUR/tCO2	Own calculations based on UBA (see Chapter 4)

Table 15: Calculation of the potential costs of a CO_2 price on emissions associated with housing loans

Calculations			
Calculation steps	**Data point**	**Value**	**Unit**
(1)*(2) = (8)	average m^2 financed through loans	466,309,742.95	m2
(8)*(3) = (9)	living space-related energy consumption of the m^2a financed through loans	78,806,346,557.88	kWh
(9)*(4) = (10)	Emissions of energy consumption of the m^2a financed by loans	46,889,776.20	tCO2
(11)*(6)= (12)	Cost scenario 1	281,338,657.21	EUR/year
(11)*(7) = 1(3)	Cost scenario 2	4,642,087,843.99	EUR/year
(1)*(5) = 1(4)	Interest payable	25,222,950,000.00	EUR/year
(12)/(14) = (15)	Share costs Scenario 1 of annual interest payments	1.1	%
(13)/(14) = (16)	Share costs Scenario 2 of annual interest payments	18.4	%